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Baffle Box Effectiveness Monitoring Report

Stormwater Academy

Final Report
Baffle Box Effectiveness Monitoring Project
DEP Contract No. S0236

For

Florida Department of Environmental Protection

And

Sarasota County Board of County Commissioners
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Executive Summary

GPI Southeast, Inc. (GPI-SE) was engaged by Sarasota County using funding from the Florida Department of Environmental Protection (FDEP) to determine the pollutant removal effectiveness of Type 1 and Type 2 baffle box BMPs. Type 2 baffle boxes have horizontal sieve screens above the pipe inverts so that floating organic matter and suspended sediments can be trapped above the water filled vaults. The design hypothesis for the screen is that organic matter trapped above the water will not leach nutrients into the water filled vault below. Type 1 baffle boxes do not have horizontal sieve screens, rather, they have swinging vertical screens that are ineffective for capturing debris.

A mass loading methodology was developed for long term monitoring and evaluation of the mass removal of stormwater pollutants by baffle boxes and applied to four full scale field installations in Florida. Two Type 1 baffle boxes in Stuart and two Type 2 baffle boxes were monitored, one in Rockledge and one in Sarasota. A primary objective of the monitoring was to determine if Type 2 baffle boxes were more effective than Type 1 baffle boxes at removing nutrient mass loadings associated with organic debris trapped in the screens. All four baffle boxes were monitored for over two years for seven or more storm events using a combination of influent and effluent autosamplers to measure water column pollutants as Event Mean Concentrations (EMCs), and manual cleaning of sediment and debris from screens and vaults to measure masses of settleable and floating pollutants. Fourteen pollutants were monitored under this program, but the principal pollutants of concern were Total Nitrogen and Total Phosphorus.

A quantitative evaluative methodology was devised to estimate and compare the total pollutant mass removal in the water column, bottom chamber material, and strainer screen material trapped in a baffle box. Results from monitoring the four baffle boxes are shown in Table 1.

The results of this study clearly demonstrated that Type 2 baffle boxes are more effective than Type 1 baffle boxes for removing TN and TP from stormwater runoff. The improved effectiveness is attributed to the horizontal screens used in Type 2 baffle boxes. The mass of nutrient material collected in the screens exceeded the mass of nutrients in the water column. At both Type 2 baffle box locations there were significant masses of leaves collected from the vault boxes, indicating that the screens were only partially effective in removing leaves from stormwater flows.

Site	Baffle Box Type	TN Mass Removal Efficiency (%)	TP Mass Removal Efficiency (%)	TN EMC Removal Efficiency (%)	TP EMC Removal Efficiency (%)	Fecal Coliform EMC Removal Efficiency (%)
Parkway Blvd, Stuart	1	0.03	0.06	5.60	-15.30	-4.2
Lincoln Lane, Stuart	1	1.00	4.50	-8.30	1.50	-89
Average Type 1		**0.50**	**2.30**	**-1.35**	**-6.90**	**-47**
Little John Lane, Rockledge	2	28.10	19.40	-11.30	-8.20	-249
Oriole Drive, Sarasota	2	10.00	11.60	30.60	21.60	13.1
Average Type 2		**19.05**	**15.50**	**9.65**	**6.70**	**-118**

Table 1 – Baffle box pollutant removal efficiencies

Note: TN and TP mass removal efficiencies for Type 2 baffle boxes are from watersheds with at least 44% tree canopy coverage. Since the majority of the gross solids collected in Type 2 baffle boxes was leaf material, watersheds with less than 44% tree canopy coverage will have lower mass removal efficiencies than shown in Table 1.

Both Type 1 and Type 2 baffle boxes showed net exports of fecal coliforms. Interevent sampling of Type 2 vault box water showed anaerobic conditions indicative of biological decomposition of organic material (predominantly leaves) leading to bacterial growth.

Monitoring results definitively showed that when performing an assessment of pollutant removals by baffle boxes, one must be cognizant of the materials not captured by typical autosamplers, including larger size sediment particles, large floating and suspended organic matter, and the pollutants associated with these materials. Using water column EMCs as the sole measure of performance can significantly underestimate loading reduction of stormwater constituents.

Upstream watershed characteristics greatly influence the mass removal efficiency of baffle boxes. The use of Type 2 baffle box BMPs are recommended when:

1. The pollutants targeted for reduction are nutrient based, and
2. There are no upstream BMPs such as ponds, exfiltration trenches, swales, inlet traps, or other filtration unit processes, and
3. The streets in the watershed have curb and gutters, and
4. The tree canopy coverage in the watershed exceeds 25%.

Background

Urban stormwater is an aqueous matrix containing a highly heterogeneous ensemble of solid components that span a size range from dissolved and colloidal to tens of centimeters (Roesner et al., 2007; Rushton et al., 2009). Stormwater solids include suspended sediment, bedload material transported by ablation, and large floating and suspended materials including grass, leaves, twigs and human derived trash. The size, density, and organic and inorganic composition of stormwater solids are highly variable. These factors greatly affect solids transport in conveyance systems and the amenability of stormwater solids to treatment through physical processes of skimming, straining, sedimentation, and filtration.

Although significant effort has been expended in characterizing solids removal by stormwater treatment devices, an approach is lacking that can unify the disparate components of stormwater solids in an integrated monitoring and evaluation framework. A number of factors hamper this effort. Urban stormwater runoff has extremely variable flowrates. The mass and composition of stormwater solids can change significantly over the course of single runoff events, and are influenced by factors including soil type, topography, land use, and magnitude of runoff (Kim and Sansalone, 2008). No single sampling technique is adequate for all types of stormwater solids. Stormwater treatment systems vary significantly in their design and configuration, and differential retention of solids components occurs at various applied flowrates. High flowrates can scour and remove previously deposited solids. These factors make it difficult to develop standardized monitoring protocols that represent solids content across the entire range of solids size and density (Clark et al., 2009; Strecker et al., 2001). Stormwater solids are also significant in affecting the fate and transport of urban stormwater constituents that sorb to stormwater solids or that are elemental components of the solid material itself. Stormwater constituents associated with solids include nitrogen (Taylor et al., 2005), phosphorus (Settle et al., 2007), heavy metals (Davis and Birch, 2009; Sansalone and Ying, 2008; Herngren et al., 2005), pathogenic indicator organisms (Characklis et al., 2005), and polycyclic aromatic hydrocarbons (Lau et al., 2009; Jartun et al., 2008; Hwang and Foster, 2006; Brown and Peake, 2006). Stormwater loadings of these constituents are a significant driver of impaired water quality and are inseparably linked to the retention of stormwater solids by treatment devices.

A standardized system for classifying stormwater solids was recently proposed based on particle sizes (Roesner et al., 2007). The size categories of stormwater solids were defined as *dissolved* (<2μm), *fine* (2-75μm), *coarse* (75μm–5 mm) and *gross* (> 5mm). The 2μm filter is similar to nominal filter pore sizes used in standard total suspended solids analyses, and delineates dissolved and colloidal materials that are typically not removed in sedimentation-based treatment devices. The No. 200 Sieve (75 μm) is the dividing boundary of *fine* and *coarse* stormwater solids and is the Unified Soil Classification System (USCS) divide defining the division between silt and sand (ASTM, 2006). *Fine* stormwater solids include clay, silt, and organic detritus from decomposition of larger organic materials. The No. 4

Sieve (5 mm) divides *coarse* from *gross* stormwater solids, and distinguishes between sand and gravel in USCS. *Coarse* solids include sand sized sediment and larger inorganic solids, organic detritus, larger organic solids such as leaf components, and human derived solids. *Gross* solids larger than 5mm include coarse sediment, organic matter such as twigs, leaves, grass, and pine needles, and human derived solids such as plastics, paper containers, styrofoam, and glass.

The ability of treatment devices to remove constituents of urban stormwater has traditionally focused on reduction of concentrations in flow weighted water column samples. For example, the International BMP Database provides an extensive compilation of performance evaluations of stormwater treatment devices for numerous water quality parameters (ASCE, 2009) and monitoring guidance for producing appropriate data sets (EPA, 2002). The primary performance metric employed by the database is flow weighted composite samples of influent and effluent water column, defined as EMCs. Autosampler-based EMC data are commonly used in many evaluations of stormwater treatment performance (Lee at al., 2007; Kim et al., 2005).

The traditional EMC approach is based on the use of autosamplers to collect flow composited samples of influent and effluent. A weakness in using EMCs is that autosamplers cannot sample the entire range of stormwater solids. This report uses an approach based upon the recommendations of the ASCE Guidelines for Monitoring Stormwater Gross Solids (Rushton, et.al. 2009) to estimate baffle box pollutant removal on a mass removal basis, including a description of a specifically designed monitoring program and a quantitative evaluative methodology. The goal of this approach is to measure masses of pollutants 1) in the water column using traditional EMC values and conversion factors, 2) in the sediment and herbaceous material accumulated in the bottom chamber, and 3) in the sediment and herbaceous material collected in the screens above the water. Summing of the masses removed continuously over a two year period will enable calculation of annual mass removal efficiency. Using a mass based efficiency calculation will give a more accurate evaluation of baffle box performance than just an EMC based calculation.

Experimental Evaluation

Baffle Box Technology

The baffle box is a structural stormwater treatment device that contains a series of settling chambers separated by baffles (Fig. 1). The unit processes utilized are sedimentation and filtration. In Florida, baffle boxes are used in retrofit scenarios where typical new development BMPs cannot be employed. A baffle box can be used with single or multiple inflow pipes and in offline or online designs. The “Type 2” baffle box is distinguished from the “Type 1” baffle box in that the Type 2 contains a sieve screen located above the water filled bottom chambers and collects larger floating and suspended materials.

Figure 1- Schematic of Type 2 baffle box showing sieve screen

Capture of stormwater sediment particles through the sedimentation unit process in a baffle box is a function of the particle size and density. Larger stormwater particles that move by ablation along the bottom of the influent pipe immediately settle into the chambers upon entry into the baffle box. Organic matter has a lower density than inorganic particles, making the capture of an equivalent size organic particle less likely than an inorganic particle with intrinsic density of 2.5 g/cc (Kayhanian, et al., 2008). Organic material consisting of ground up organic debris cannot be distinguished or separated from inorganic sediment. Standard methods used for TSS analysis do not differentiate between organic and inorganic sediments, leading to inherent inaccuracies in calculations of organic loadings in stormwater based solely on TSS measurements. In this study, the Percent Organic Matter test was used to determine the fraction of the dry mass of solids collected in the baffle boxes that was organic.

The Type 2 baffle boxes contain a basket-shaped strainer screen with 1.3 to 2 cm openings that is mounted above the bottom chamber baffles (Fig. 2). The strainer screen provides a second mechanism for removal of stormwater solids. Larger floating and suspended materials, including leaves, pine needles, and natural and human derived trash and debris, are retained on the screen by physical straining. Material captured in the baffle box screen during runoff events is held above the surface of the water column in interevent periods, thus reducing the potential for leaching of constituents into the water column and

Figure 1 - Sieve strainer screen of Type 2 baffle box

enhancing the opportunity to dry. Material that is captured and retained by the screens can form a mat on the screen surface, reducing the effective size of openings through which runoff passes. The result is the retention of stormwater particles that are smaller than the screen openings.

Project Sites

In order to monitor a baffle box or any BMP in the field, it is critical to choose a location that allows the researcher to control the flow and water quality variables to a degree that provides accurate results. Taking the laboratory to the field is difficult. Site selection criteria that were used for this baffle box monitoring program included:

- The baffle box had one influent pipe and one effluent pipe.
- There were no base flows through the pipes.
- There were no bypass flows during large storms.
- There were no backflows into the baffle box from adjacent streams, bays, or ocean.
- The baffle box was not located in a roadway. Access dictated a location outside of the pavement for safety reasons.
- For the rain gauge and solar panels to operate there was no tree coverage over the site.
- The autosamplers are expensive equipment. A site was chosen in neighborhoods where the vandalism potential was low. There was room for a theft proof enclosure to be placed in a yard or next to a road. Adjacent property owners were canvassed to ensure their cooperation with technicians accessing equipment at any hour.
- Technicians were able to park vehicles adjacent to the site to perform collection activities. Lane closures of roadways were avoided.

- In this study leaf collection was a major objective for the Type 2 baffle boxes. Therefore drainage basins were chosen for the Type 2 boxes that had significant tree canopy coverage.
- All four drainage basins were chosen with primarily residential land use in order to have similar pollutant loadings.
- The interior of the BMPs had sufficient clearance and access to enable a technician to install equipment and take samples.
- The sites were within reasonable driving distance of technicians making weekly visits to inspect and calibrate equipment.
- At the Type 2 locations there were no upstream BMPs in the drainage basin, including roadside swales that would filter pollutants, especially gross solids, before they entered the baffle box. The roadways had curb and gutters.

The monitoring study was conducted on four full-scale baffle boxes in Florida. Characteristics of the baffle boxes that were monitored in this study are summarized in Table 2. The Rockledge and two Stuart sites were located on the eastern central coast of Florida. Sutron Corporation was used to collect data at the three east coast sites. The Sarasota site was located on Florida's southwest coast. Due to the long distances between Sarasota and the east coast sites, a Sarasota based PBSJ office was chosen for data collection at the Oriole Drive site. The laboratories used for analyses of samples from the east coast sites were Harbor Branch Environmental, Inc., Genapure Analytical Services, Inc., and Mactec Engineering and Consulting, Inc. The laboratories used for the Oriole Drive sample analysis of the Sarasota site were Sanders Laboratories, Inc., U.S. Biosystems, and Mactec Engineering and Consulting, Inc.

All four baffle boxes evaluated in the study had a single entrance pipe and a single discharge pipe. Land uses of the contributing drainage basins were single family residential and light commercial as summarized in Table 3. Delineations of the contributing watersheds were shown in Figs. 3 through 6.

Little John Lane Baffle Box (Rockledge) – Type 2

The Little John Lane Baffle Box site receives runoff from a 16.18 acre drainage basin. The land use is single family residential with Type A soils and 0.4 acre lots. The streets have curb and gutter. There is a 44% tree canopy coverage, principally oak trees, in the basin that contribute to high levels of leaves trapped in the baffle box. All of the runoff is transported by sheet flow along the gutters until it reaches the intersection of Little John Lane and Rockledge Drive where 2 grated inlets intercept the water and small pipes convey the water to the baffle box. The grade of the land is steep, falling 15 feet from Brevard Ave. eastward to the Indian River.

Oriole Drive Baffle Box (Sarasota) – Type 2

There are 21 acres in the Oriole Drive drainage basin consisting of single family land use. The lots are ¾ to 1.0 acre in size. The roads have curb and gutters and storm drains throughout the basin. Oak and pine tree coverage in the basin is 86.8%. The grade of the land is moderate from east to west. Soil types in the area are B/D.

Lincoln Lane Baffle Box (Stuart) – Type 1

The drainage basin for this baffle box consists of 102.91 acres of mixed used residential, light industrial, and park land uses. Almost all of the basin has curb and gutters. A well developed stormdrain pipe system conveys water throughout the basin. The basin topography is flat with long times of concentration. In the northern end of the basin there are both a regional and two private wet detention ponds providing treatment for 27.85 acres. This treated area has curb and gutters. Downstream of those wet ponds there is no other stormwater treatment for the remaining 75.06 acres. Ground water west of the railroad tracks is low due to the low elevation of the adjacent Poppleton Creek. The soils in the basin are classified as Type A soils with high infiltration rates. Tree canopy coverage in the basin area downstream of the ponds is 9%. The trees are mostly isolated and scattered throughout the basin. Few of the trees are adjacent to streets where leaves could easily enter the storm drains. During the first seven months of monitoring, which corresponded to a drought period, the baffle box had no base flows from the upstream ponds. During the remainder of the monitoring period after the drought broke there were base flows measured through the baffle box.

Parkway Lane Baffle Box (Stuart) – Type 1

This baffle box receives runoff from 23.28 acres of single family residential property. There are no curb and gutters and no roadside swales. Most of the runoff in the basin is conveyed by sheet flow along the streets. There is one 900 foot long run of pipe leading to the baffle box. North of 7th Street, between SE Madison and SE Fini Drive, there is a vegetated swale in the alley receiving water from the northern parts of the drainage basin. The swale has a number of berms to create a series of cascading retention swales that lead to SE 7th. The ground water in much of the basin should be low due to the low elevation of the adjacent Krueger Creek. Soils in the drainage basin are predominantly B soils with moderate infiltration. There is only 7.5% tree coverage in the drainage basin. Topography in the basin is flat with low flow velocities and little erosion.

Site	Baffle Box Type[1]	Inner Length, ft.	Inner Width, ft.	Plan Area, ft^2	Number of Chambers
Little John Drive, Rockledge City	2	9.83	5.00	49.2	3
Oriole Drive, Sarasota	2	9.00	5.00	45.0	3
Lincoln Avenue, Stuart City	1	9.00	4.17	37.5	3
SE Parkway Drive, Stuart City	1	9.00	4.17	37.5	3

[1]Type 1 does not include strainer screen; Type 2 includes strainer screen.

Table 2 - Four baffle boxes monitored in study

Site	Baffle Box Type	Drainage Basin (ac)	Curb and Gutter	Tree Coverage (%)	Upstream BMP
Parkway Blvd	1	23.28	No	9	Swales
Lincoln Lane	1	102.91	No	7.5	Ponds
Little John Lane	2	16.18	Yes	44	N/A
Oriole Drive	2	21	Yes	86.8	N/A

Table 3 - Watershed characteristics

Figure 2 - Rockledge baffle box project location and watershed

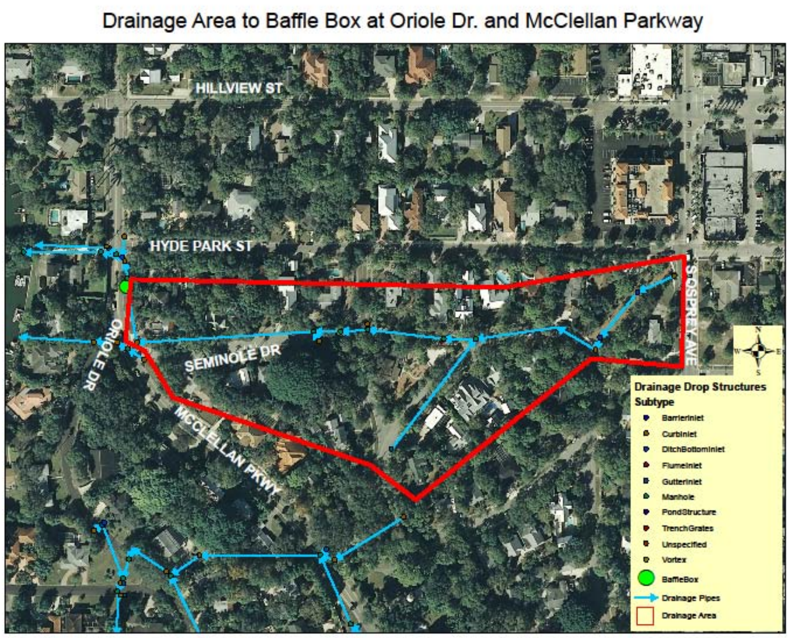

Figure 3 - Sarasota baffle box project location and watershed

Figure 4 - Lincoln baffle box project location and watershed

Figure 5 - Parkway baffle box project location and watershed

Monitoring Approach

The primary objectives of this project were to 1) provide a comprehensive representation of all pollutant masses removed by the baffle boxes, 2) compare the performance of Type 1 vs. Type 2 baffle boxes, and 3) provide recommendations for site selection criteria for use of baffle box BMPs. The monitoring program was developed to include three separate components:

- *Water column*: autosamplers to collect flow composited samples of baffle box influent and effluent in runoff events to develop EMCs;
- *Bottom chamber material*: discreet monitoring to determine total accumulated mass and to perform physical and chemical analyses; and
- *Strainer screen materials*: quantifying total volume and captured mass of captured materials including gross solids components and to perform physical and chemical analyses of representative samples.

To relate and integrate monitoring results for all three solids components, continuous flow monitoring over the whole test period allowed matching the three sampling components to their appropriate time frames and volumetric data. For instance, water column samples were matched to storm event flows that were high enough to trip autosampling. Gross solids samples were matched to total volumes of flow between sampling events, including the storms too small to trip the autosampler. Based upon the completeness of flow data at each baffle box site, a common time period was chosen at each site to combine the water column and gross solids data, enabling total mass calculations over the common time period.

Multiple influent and effluent EMC pairs were used to represent overall water column removals over the common time period. The materials that accumulated in the bottom chamber and strainer screen were not amenable to event-based autosampler monitoring, requiring a different sampling approach. For solids collected in the bottom chamber and strainer screen, the total mass of solids that accumulated during the study period was determined by completely cleaning the baffle box at the start and end of the common study period, and by accounting for all mass removed through during the study period ($t_{start} < t < t_{end}$). The common period of operation was defined by the initial baffle box cleanout (t_{start}) and the final cleanout (t_{end}). Physical and chemical analyses of accumulated solids in the bottom chamber and strainer screen materials was performed on materials collected at the end of the study period and was not able to account for decomposition of collected material that may have occurred during storage.

Water Column Sampling and Analysis

Water column sampling and analyses methods were described in the Baffle Box Testing Program Final Quality Assurance Project Plan (QAPP) (Sutron Corporation, 2006) (QAPP), approved by FDEP. Baffle boxes were equipped with a rain gauge (ISCO 674), two refrigerated Portable Sequential Samplers (ISCO 6712), and an Area-Velocity Flow Module (ISCO 750). Flowlink software was used to program the flow meter, collect precipitation data, and instruct autosamplers to initiate sample collection when cumulative event precipitation reached 0.508 cm. Autosampler initiation was also constrained by analyte holding times and laboratory availability. Flow composited samples were poured into prepared HDPE containers, placed on ice and shipped to the analytical laboratory within allocated holding times, except where noted. Seven or more individual runoff events were monitored at each baffle box and a flow record was maintained through the study. Analyses performed on water column samples are listed in Table 4. Composite samples were analyzed using EPA methods for Total Suspended Solids (160.2), Total Kjeldahl Nitrogen (351.2), Ammonia (350.1), Nitrate+Nitrite (353.2), Total Phosphorus (365.1), Orthophosphate (365.1), and heavy metals (EPA 200.7). Grab samples were utilized to test for Fecal Coliforms (SM 18-9222D).

Per the QAPP, sampling events were initially set to occur after 0.2 inches of rain in a 30 minute time period. Sampling of several storms of this small magnitude resulted in sampling volumes too small to send to the lab. In order to meet the temporal nature of rainfall at the Rockledge and Stuart sites, several adjustments to the tripping criteria were tried, with the final criteria being a 0.4-inch storm in 15 minutes.

Holding times were the maximum time between sample collection and lab analysis. Holding times defined the time windows that could be used for autosampler collection, technician travel to site, sample preparation, shipping, lab receipt, and lab analysis. The QAPP defined holding times for the various parameters analyzed. The minimum holding times for water column samples were 4 hours for fecal coliform and 48 hours for Orthophosphate. Laboratories generally do not work overtime, meaning only storms occurring before 12:00 P.M. could be sampled to meet the fecal coliform holding time. Many storms in Florida occur in the afternoon and evenings. For the first few months numerous afternoon storms were missed due to this holding time limitation. After consultation with FDEP the QAPP was amended to allow testing for fecal coliforms with grab samples independently from the autosampler samples and fecal tests became optional if the technician could reach the site during the morning hours. This QAPP revision allowed collection of storm samples any time of the day or night.

At the Rockledge site a problem was encountered with the flow meter incorrectly recording data. The meter was recalibrated, then replaced, but still was showing erratic flows during storms. An inspection of the downstream pipe showed numerous spider webs hanging from the pipe soffit that were full of leaves. During storms these dangling spider webs over the flow meter caused interference with the readings. After removing the spider webs no further problems were encountered with the flow meter.

At the Sarasota site there were several set up problems and equipment failures in the first year. As a result, only one of the first five sampling events met QAQC protocols and was fully usable.

Parameter	Matrix	Units	Method	Precision (% RSD)	Accuracy (% Recovery)
Sieve Analysis (5 screens: #20, #40, #80, #100, <#200)	Sediment/Solid	N/A	ASTM D422	N/A	N/A
Percent Organic Matter	Sediment/Solid	%	ASTM D2974	N/A	N/A
Density	Sediment/Solid	g/cc	ASTM D2937	N/A	N/A
Total Nitrogen	Sediment/Solid	mg/kg	EPA/CE81	12	64 - 136
Chemical Oxygen Demand	Sediment/Solid	mg/kg	EPA 410.4	12	71 - 136
Total Phosphorus	Sediment/Solid	mg/kg	EPA 365.4	14	70 - 132
Mercury	Sediment/Solid	mg/kg	EPA 7470	12	67-141
Aluminum	Sediment/Solid	mg/kg	EPA 6010	15	80 - 116
Barium	Sediment/Solid	mg/kg	EPA 6010	9	88 - 111
Chromium	Sediment/Solid	mg/kg	EPA 6010	7	88 - 112
Cadmium	Sediment/Solid	mg/kg	EPA 6010	8	89 - 113
Iron	Sediment/Solid	mg/kg	EPA 6010	18	79 - 138
Nickel	Sediment/Solid	mg/kg	EPA 6010	7	85 - 111
Zinc	Sediment/Solid	mg/kg	EPA 6010	18	80 - 125
Copper	Sediment/Solid	mg/kg	EPA 6010	17	84 - 120
Acenaphthylene	Sediment/Solid	µg/kg	EPA 8270	22	36 - 122
Benzo(a)pyrene	Sediment/Solid	µg/kg	EPA 8270	9	55 - 117
Benzo(g,h,i)perylene	Sediment/Solid	µg/kg	EPA 8270	13	56 - 123
Fluoranthene	Sediment/Solid	µg/kg	EPA 8270	20	50 - 126
Fluorene	Sediment/Solid	µg/kg	EPA 8270	14	40 - 131
1-Methylnaphthalene	Sediment/Solid	µg/kg	EPA 8270	18	25 - 113
Naphthalene	Sediment/Solid	µg/kg	EPA 8270	21	27 - 112
Pyrene	Sediment/Solid	µg/kg	EPA 8270	13	51 - 121

Table 4 – Parameters measured

Bottom Chamber Sampling and Analysis

Samples collected from Type 1 baffle box bottom chambers were almost entirely sediment or decomposed organic material. At the Lincoln Lane site 3,014 pounds of material were collected over the sampling period. At the Parkway Lane site only 87 pounds of material was collected over the sampling period.

Bottom chamber sampling and analyses methods were described in the QAPP. The bottom chambers were sampled and cleaned at the end of each sampling period on the dates shown below. There was so little sediment accumulation in the Parkway baffle box that only one cleaning operation was performed at the end of the project. Cleanout masses are shown in Tables 15 – 18.

At the Sarasota site only one bottom chamber sediment sample was correctly performed, on 11/15/2007. On 1/27/2009 County crews inadvertently cleaned the bottom chamber and sieve screens without the knowledge of PBSJ. Two other baffle boxes not associated with the project were also cleaned on the same day and the materials from all three baffle boxes were mixed and deposited at a County facility. Samples were taken of the mixed material from all three baffle boxes; however, sediment sampling results for this event were considered to be inaccurate.

Site	Cleanout #	Date
Little John Drive, Rockledge City	1	11/6/2007
	2	3/9/2009
Oriole Drive, Sarasota	1	11/15/2007
	2	1/27/2009
Lincoln Avenue, Stuart City	1	12/6/2007
	2	2/26/2009
SE Parkway Drive, Stuart City	1	2/26/2009

Table 5 – Dates of box cleanouts

Before sampling, the depth of sediment was measured at multiple points in each chamber and total bulk volume was calculated using the average depth and chamber cross sectional areas. Sediment sampling and analyses were conducted following recommended procedures (EPA, 2001) designated in the QAPP. For each chamber, numerous sediment samples were collected with a Stainless Steel Petite Ponar, mixed, placed into Ziploc bags for geotechnical analyses, into glass bottles for inorganics and metals analyses, and into glass bottles with Teflon lids for organics analyses. Ziploc bag samples for each separate chamber were shipped to the geotechnical laboratory. In the laboratory, a single composite sample was assembled for geotechnical analyses by combining samples from each bottom chamber in proportion to the volume accumulated in that chamber. Geotechnical analyses were conducted according to American Society for Testing and Materials methods (ASTM, 2009) and included wet and dry density (D2937), percent organic matter (D2974), and sieve analysis for Particle Size Distribution (D422). Glass bottle samples for each separate chamber were placed on ice for shipment. In the analytical laboratory, single composite samples for chemical analyses was assembled by combining material from each of the three chambers in proportion to the volume accumulated in each chamber. Analyses were conducted by the following EPA methods: Chemical Oxygen Demand (410.4), Total Nitrogen (351.2/353.2), Total Phosphorus (365.4), metals (6010), mercury (7470), and Polycyclic Aromatic Hydrocarbons (8270). The geotechnical and chemical analyses results for the composite samples were used to represent the entire mass of solids removed from the bottom chambers at the end of the common study period (t_{final}). A list of analyses performed for material collected from the bottom chambers of the baffle boxes is listed in Table 4.

Field sampling showed that materials in the bottom chambers of the Rockledge and Sarasota baffle boxes were a mixture of sediment and leaves that had not been trapped in the screen. See photographs in Appendix A. Laboratory analyses of composite bottom chamber samples indicated the percentage of the bottom chamber materials that were organic were 12.6% to 16.7% for Rockledge and 55.8% for Sarasota baffle boxes. Percent Organic Material collected in the Stuart baffle boxes were 5.8% for Lincoln, and 7.5% for Parkway. The higher levels of bottom chamber organic content at the Rockledge and Sarasota baffle boxes were ostensibly due to leaf and organic materials that had bypassed the sieve screen or to finer organic breakdown products that had passed through the screen.

Results of the bottom chamber sampling were used to represent the entire mass of solids removed from the bottom chambers from all four baffle boxes over the common study periods.

Sieve Screen Sampling and Analysis

Type 2 baffle boxes screens are designed to trap gross solids, primarily organic debris, and keep the material above the water in the vault, thus preventing nutrients from leaching into the vault water and out to receiving waters. At the two sites monitored, the organic debris was almost entirely leaves. There was no significant accumulation of grass clippings in the debris. Observations of collected mass in both Type 2 baffle boxes showed that after leaf mass collected just a few centimeters on the screens, the screen openings became blocked and the leaves became fine filters that trapped sediment as well as fine organic debris. The resulting mass of trapped material and sediment had very low porosity causing water to become trapped in the matted material and ponding above the vault water level in a micro pond in the basket. Interevent observations showed that the organic material stayed moist and sometimes submerged for days after a rain event. Ponded water in the screen was turbid even though water in the vault was clear, indicating that nutrients were leaching out of the organic debris. In addition, material collected from the vault chambers had a high number of leaves, demonstrating that the screens were only partially successful in keeping organic debris out of the water filled vaults.

Sieve screen sampling and analyses methods were described in the QAPP. The material captured on the strainer screen was removed nine and five times over the course of the study for Rockledge and Sarasota, respectively. Total masses cleaned are shown in Tables 15 – 18.

Site	Cleanout #	Date
Little John Drive, Rockledge City	1	3/13/2007
	2	3/28/2007
	3	4/20/2007
	4	8/1/2007
	5	11/6/2007
	6	2/14/2008
	7	6/18/2008
	8	9/9/2008
	9	3/9/2009
Oriole Drive, Sarasota	1	2/13/2007
	2	7/26/2007
	3	11/15/2007
	4	7/17/2008
	5	1/27/2009

Table 6 – Sieve screen cleanout dates

This material was a combination of leaves, organic debris, and sediment. For each removal event, the bulk volume of accumulated material was first estimated from the average depth and plan area of the strainer screen. The material was placed in plastic bags and weighed in an as-collected state. Strainer screen materials were processed for geotechnical and chemical analyses at the conclusion of the common study periods (t_{end}). After bulk volume determination, the accumulated material was removed from the screens, weighed and transported to an indoor processing facility. All of the material was spread out at approximately two-inch thickness on a polyethylene sheet to air-dry for 48 hours. The material was then mixed and spread to a thickness of ½ inch and air-dried for an additional 72 hours. The material was mixed again, and human-derived trash was removed and quantified.

The material was then divided into a grid with 20 regions. A large polypropylene scoop was used to collect 20 individual samples that were placed in empty polypropylene beakers (empty weights were recorded before material was collected). The beakers containing the sampled material were dried for several days until the material was sufficiently dry to enable the fine sediment particles to be separated from the larger materials (predominantly leaves) using a 1mm mesh non metallic screen. The separation process was accomplished by moving the large material gently back and forth over the 1 mm grid screen, such that smaller particles were able to dissociate from the larger material while the leaves did not break apart. The separation screen was placed over a tared polypropylene beaker. The weight of the tared collecting beaker plus the material passing through the 1 mm screen was recorded before sending samples to geotechnical and analytical laboratories. The remaining mass of the large sized material, from which the smaller sediment was derived, was removed and recorded before preparing samples for shipment to geotechnical and analytical laboratories.

Samples of material > 1mm and < 1 mm were placed in Ziploc bags and shipped in a cooler to the geotechnical laboratory. Geotechnical analyses were conducted according to ASTM methods and included wet and dry density (D2937), percent organic matter (D2974), and sieve analysis for Particle Size Distribution (D422). Samples of > 1mm and < 1 mm materials were placed in glass bottles for inorganics and metals analyses, and glass bottles with Teflon lids for organics analyses, and shipped on ice to the analytical laboratory. Analyses were conducted by the following EPA methods: Chemical Oxygen Demand (410.4), Total Nitrogen (351.2/353.2), Total Phosphorus (365.4), metals (6010), mercury (7470), and Polycyclic Aromatic Hydrocarbons (8270). The analyses used for sieve screen samples are listed in Table 4. The results of geotechnical and chemical analyses of composite samples were used to represent the entire mass of solids removed from the strainer screen of the Rockledge and Sarasota baffle boxes over the common study periods.

Performance Assessment Methodology

Storm Event Scale-Up

Mass removals for the common periods were calculated individually for three components: 1) water column runoff, 2) material accumulated in bottom chambers, and 3) material accumulated on the strainer screen. Due to sampling thresholds, equipment failures, holding time limitations, and not sampling during Tropical Storm Fay for safety reasons, water column monitoring was not conducted for all runoff events that occurred in the common study period. However total flow volumes passing through the baffle boxes were recorded during the common study period. Therefore total water column mass removals were scaled up based on the ratio of total runoff volume during the common study period to the total monitored runoff volume:

$$R = \frac{Volume_{tot}}{Volume_n} = \frac{\sum_{i=1,tot} Volume_i}{\sum_{i=1,n} Volume_i} \qquad (1)$$

where: R = ratio of total runoff volume to monitored event runoff volume (-)
tot = total runoff events in common period
n = monitored runoff events in common period
$Volume_i$ = volume of runoff event i (liter)

Estimation of Mass Removals

Total water column mass removal over the common periods were estimated as the sum of mass removals for the monitored events, scaled up to the total runoff volume treated by the baffle boxes during the study period.

$$Mass_{WCM} = \sum_{i=1,n} Volume_i * \left(EMC_{inf_i} - EMC_{eff_i}\right) * R \qquad (2)$$

where: $Mass_{WCM}$ = water column mass removal in common period, (mg)
EMC_{eff_i} = influent EMC of runoff event i, (mg/L)
EMC_{eff_i} = effluent EMC of runoff event i, (mg/L)

Mass removals of stormwater pollutants in bottom chamber materials were calculated as the product of the accumulated bulk volume, its dry bulk density, and the solids pollutant concentration.

$$Mass_{BCM} = Volume_{bcm} * \rho_{bulk,bcm} * q_{bcm} \qquad (3)$$

where: $Mass_{BCM}$ = mass removed in bottom chamber in common period, (mg)
$Volume_{bcm}$ = bulk volume of bottom chamber material removed, (liter)

$\rho_{bulk,bcm}$ = bulk density of bottom chamber material, (kg/L)
q_{bcm} = solid phase constituent concentration, (mg/)

Mass removals of stormwater constituents in strainer screen materials were calculated as the product of the accumulated bulk volume, its dry bulk density, and the solid phase concentration.

$$Mass_{SSM} = Volume_{ssm} * \rho_{bulk,ssm} * q_{ssm} \tag{4}$$

where: $Mass_{SSM}$= mass removed in strainer screen in common period, (mg)
$Volume_{ssm}$ = bulk volume of strainer screen material removed (liter)
$\rho_{bulk,ssm}$ = bulk density of strainer screen material, (kg/L)
q_{ssm} = solid phase constituent concentration, (mg/kg)

Equivalent Concentration

Traditional testing methods for the water column use an EMC measurement at the inflow and outflow points of a BMP. The difference in concentrations gives the percent removal efficiency of the device for one storm or group of storms based on the water column measurements. This method cannot be used for measuring gross solids because there is no method for measuring gross solids entering and leaving the BMP. The only measurement is mass of gross solids trapped in the BMP. Taking mass samples of gross solids upstream of the BMP would invalidate the measurement of masses trapped in the BMP.

Therefore an alternative method was used to determine the mass removal efficiency of the Rockledge baffle box. Whole mass measurements (not samples) of effluent and gross solids leaving the baffle box were taken with a specially designed screening device, see Appendix A. While this device accurately captured large floating gross solids, its ability to capture bypass sediment particles was limited to visual rather then measured quantification. Results from the bypass test showed a 99% capture efficiency for the Rockledge baffle box, i.e. the mass of leaves and sediment captured in the bypass device were only a few grams, whereas the masses captured in the baffle box were hundreds of pounds. By summing the total mass of gross solids trapped in the baffle box with the total mass leaving the baffle box, the total influent gross solids mass was calculated.

The equivalent concentration of captured solids and associated constituents is that which would occur if the captured material were homogenized and distributed uniformly into the entire volume of runoff treated during the common study period., (mg/L)

$$EC_{BCM} = \frac{Mass_{BCM}}{Volume_{tot}} \tag{5}$$

$$EC_{SSM} = \frac{Mass_{SSM}}{Volume_{tot}} \tag{6}$$

where: EC_{BCM} = equivalent concentration of bottom chamber material (mg/L)
EC_{SSM} = equivalent concentration of strainer screen material (mg/L)
(7)

Derived Efficiency

The baffle box monitoring configuration was not able to fully measure all components of stormwater solids entering and leaving the baffle boxes, precluding conventional approaches to estimating mass removal efficiency. A new approach was developed to estimate mass removal efficieny for the baffle boxes in this study, based on the assumption that the influent water column samples plus the accumulation of solids in the baffle box account for all influent discharge mass, while effluent water column samples account for all discharge mass. The calculated mass removal efficiency is here termed the Derived Efficiency, and is calculated for individual constituents over the common period:

$$DE = \frac{Mass_{BCM} + Mass_{SSM}}{Mass_{BCM} + Mass_{SSM} + Mass_{WC,Eff}} \text{ x } 100 \tag{8}$$

where: DE = derived efficiency in common period. The DE is an upper limit of removal efficiency because any passage of larger solids into the discharge would reduce the calculated efficiency.

Results and Discussion

Monitored Periods and Storm Events

Baffle box monitoring periods are shown in Table 7, along with days of operation, total treated volume, and water column scale-up factor for constituent mass. Monitored storm events are listed in Table 8, including precipitation associated with the monitored storm event and the total treated volume. A runoff volume time series for the Rockledge baffle box is shown in Figure 7, which illustrates the dates at which the individual storm event monitoring was conducted. The cumulative distribution of runoff events for Rockledge is shown in Figure 8, along with the position of the monitored storm events on the runoff volume distribution. Similar plots are shown for the Sarasota, Lincoln, and Parkway baffle boxes in Figures 9 through 14. Visual inspection of runoff distribution plots indicated that treated volumes of the monitored storm events were reasonably distributed over the runoff volumes

Site	Start Date	End Date	Number of Days	Total Volume, million gallon	Treated Runoff Volume, inch/year	Monitored Storm Volume, million gallon	Water Column Scale Up Factor
Little John Drive, Rockledge City	10/11/06	3/9/09	880	2.94	2.8	0.290	10.1
Oriole Drive, Sarasota	11/1/06	1/27/09	818	13.0	10.2	1.16	11.2
Lincoln Avenue, Stuart City	10/2/06	2/26/09	878	17.9	2.7	0.232	77.2
SE Parkway Drive, Stuart City	10/2/06	2/26/09	878	5.79	3.8	0.560	10.3

Table 7 - Baffle box monitoring periods

Storm Event Number	Little John Drive, Rockledge City			Oriole Drive, Sarasota			Lincoln Avenue, Stuart City			SE Parkway Drive, Stuart City		
	Date	Precip., in	Runoff Volume, gal.	Date	Precip., in	Runoff Volume, gal.	Date	Precip., in	Runoff Volume, gal.	Date	Precip., in	Runoff Volume, gal.
1	3/16/07	0.52	12,765	11/16/06	0.86	33,791	4/10/07	1.11	30,693	5/14/07	1.19	29,020
2	4/10/07	0.81	17,932	12/21/07	0.48	75,241	5/13/07	0.72	11,362	7/25/07	0.46	2,306
3	7/24/07	0.41	17,249	6/21/08	0.61	46,855	5/14/07	0.72	25,639	8/14/07	2.34	165,267
4	7/31/07	0.79	36,207	7/6/08	1.24	122,926	5/24/07	0.27	10,503	12/14/07	0.74	20,311
5	8/2/07	1.47	77,943	8/4/08	0.67	91,645	7/23/07	0.42	35,146	3/6/08	2.32	377,526
6	8/23/07	0.92	43,817	8/8/08	1.16	197,450	7/25/07	0.68	40,321	3/30/08	2.61	291,140
7	10/18/07	1.24	53,900	8/9/08	0.79	108,026	7/30/07	0.49	43,728	10/18/08	1.30	46,646
8	2/12/08	0.89	30,392	9/9/08	2.72	395,393	2/12/08	1.16	34,748	-	-	-
9	-	-	-	9/30/08	0.50	24,639	-	-	-	-	-	-
10	-	-	-	10/6/08	0.91	32,968	-	-	-	-	-	-
11	-	-	-	1/13/09	0.71	30,745	-	-	-	-	-	-

Table 8 – Monitored storm events

treated by the baffle boxes over the time period of the study. The flow rate data collected by flow monitors was used directly to calculate treated volume for three of the four baffle boxes; a different procedure was applied to the Lincoln Ave. baffle box volume data due to a baseflow component providing significant flow volumes on single or multiple days with zero precipitation.

Due to the sampling and monitoring failures at the Sarasota site, autosampling data was compromised on several occasions. Gross solids mass cleanout data at that location was also compromised. The mass cleaned on 1/27/2009 from the screens and bottom chamber were estimated from County records rather from PBSJ measurements. Laboratory sampling of bottom sediments were qualified as being from a combination of three baffle boxes rather than just the Oriole baffle box. The overall usefulness of data from the Sarasota site was limited and did not meet program goals. Result summaries of pollutant removals from the Sarasota site are adjusted to reflect the time periods of accurate data collection.

Data collection at the other three sites had minor problems typically encountered in field sampling, but nothing significant like the Sarasota site. Therefore, the Rockledge site data collection over the entire time period was accurate and will be referenced more heavily than the Sarasota site for summaries and conclusions.

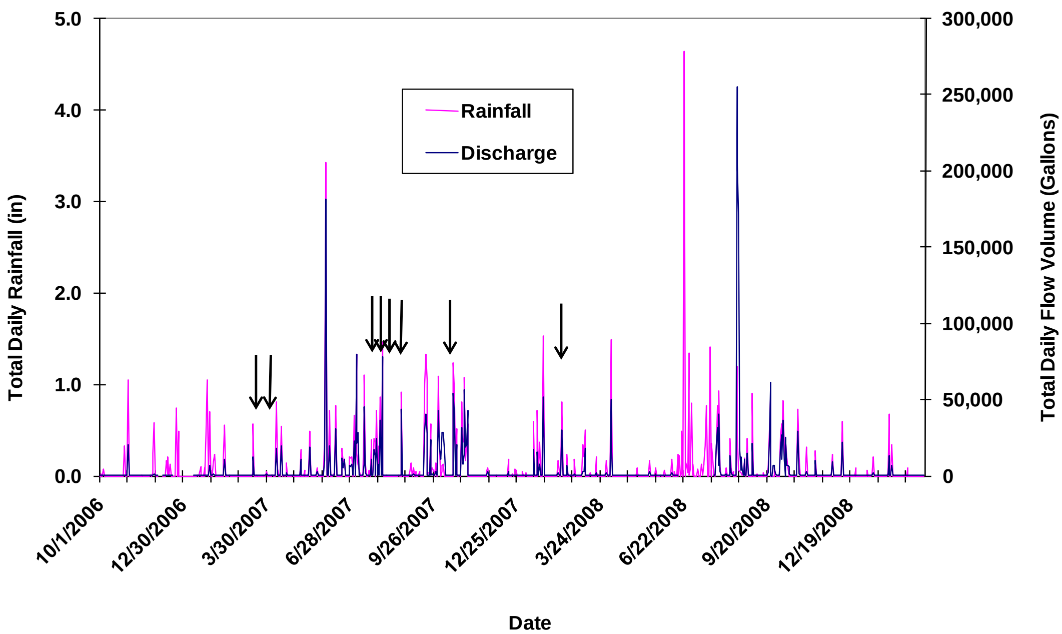

Figure 6 - Rockledge flow record showing monitored storm events

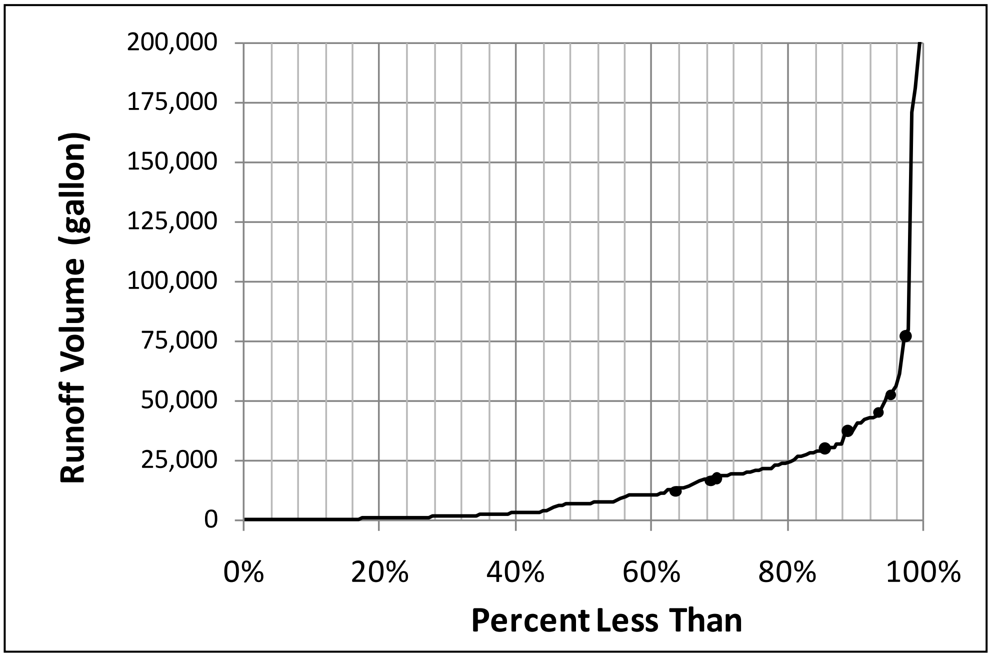

Figure 7 - Rockledge cumulative runoff distribution showing monitored storm events

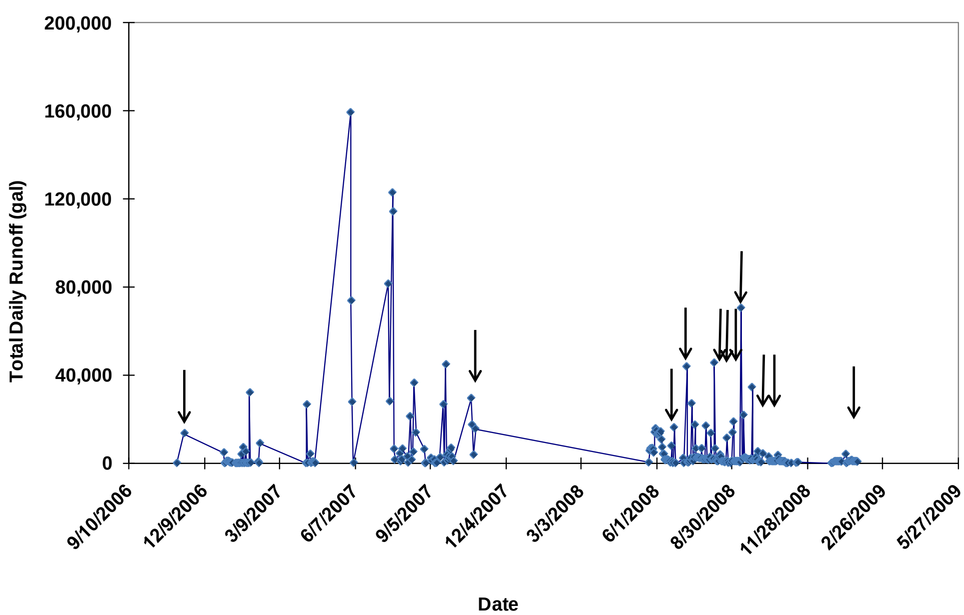

Figure 8 - Sarasota flow record showing monitored storm events

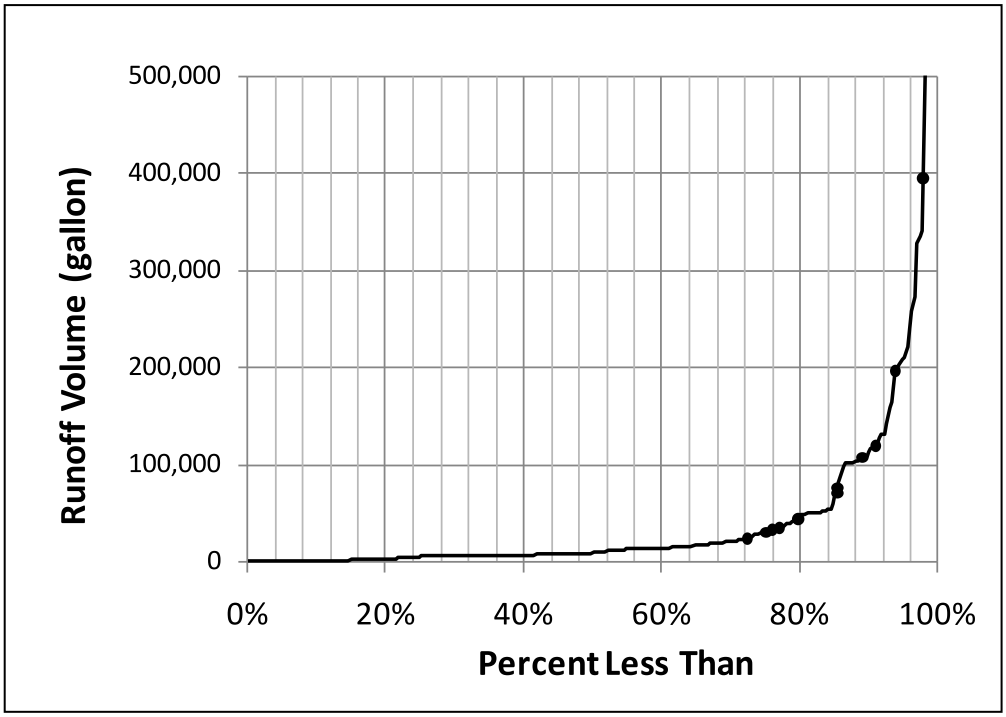

Figure 9 - Sarasota cumulative runoff distribution showing monitored storm events

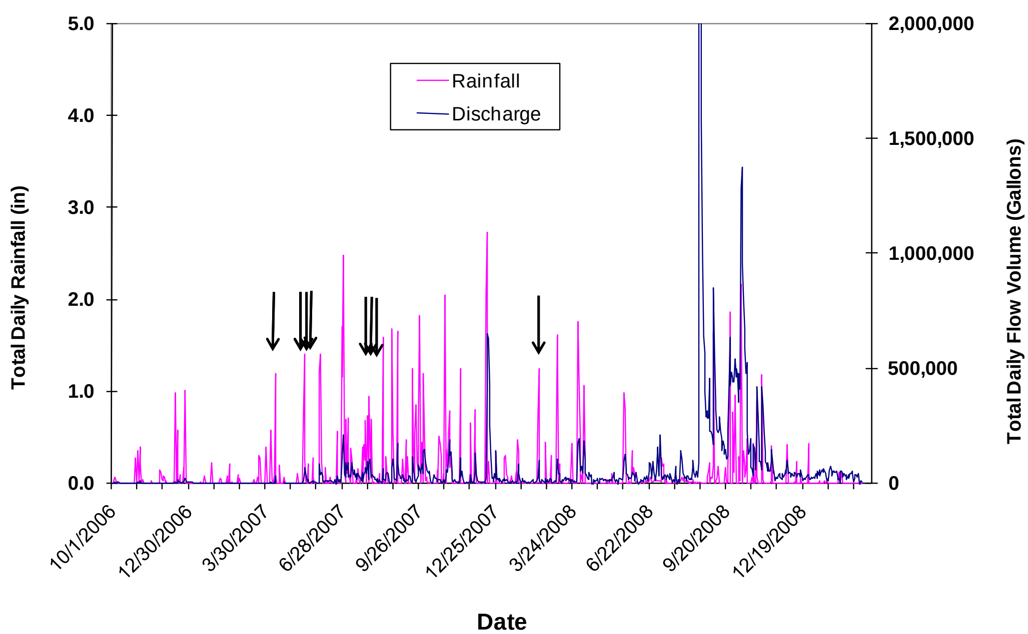

Figure 10 - Lincoln flow record showing monitored storm events

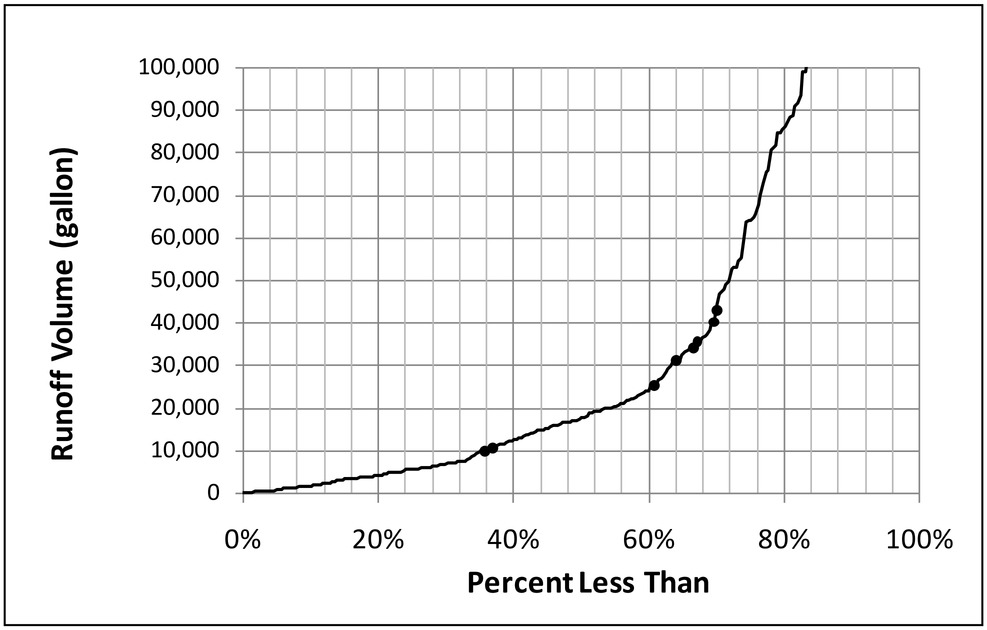

Figure 11 - Lincoln cumulative runoff distribution showing monitored storm events

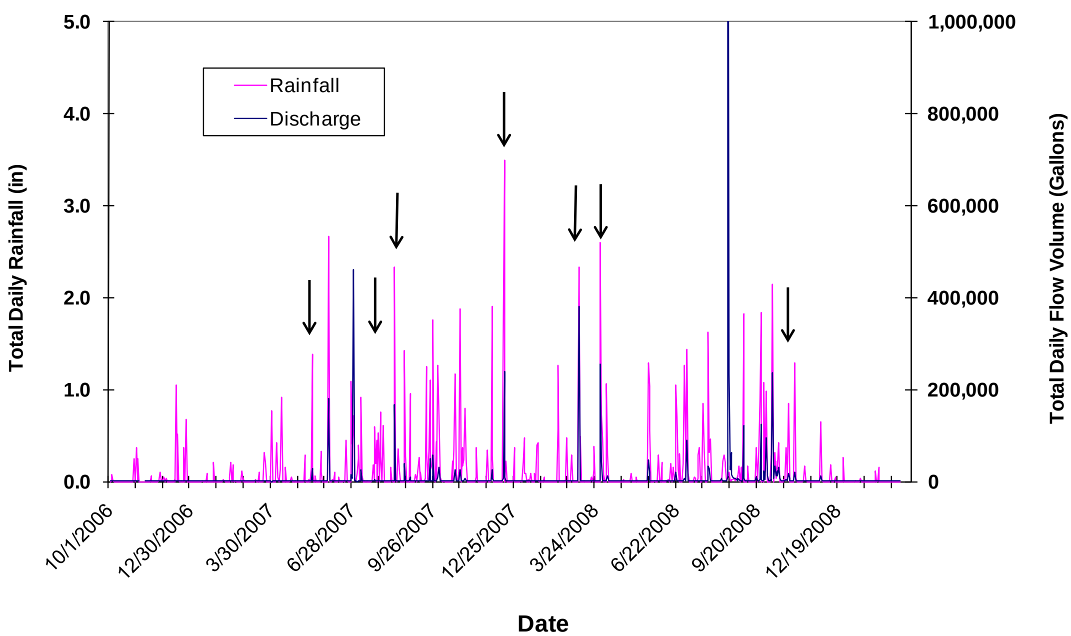

Figure 12 - Parkway flow record showing monitored storm events

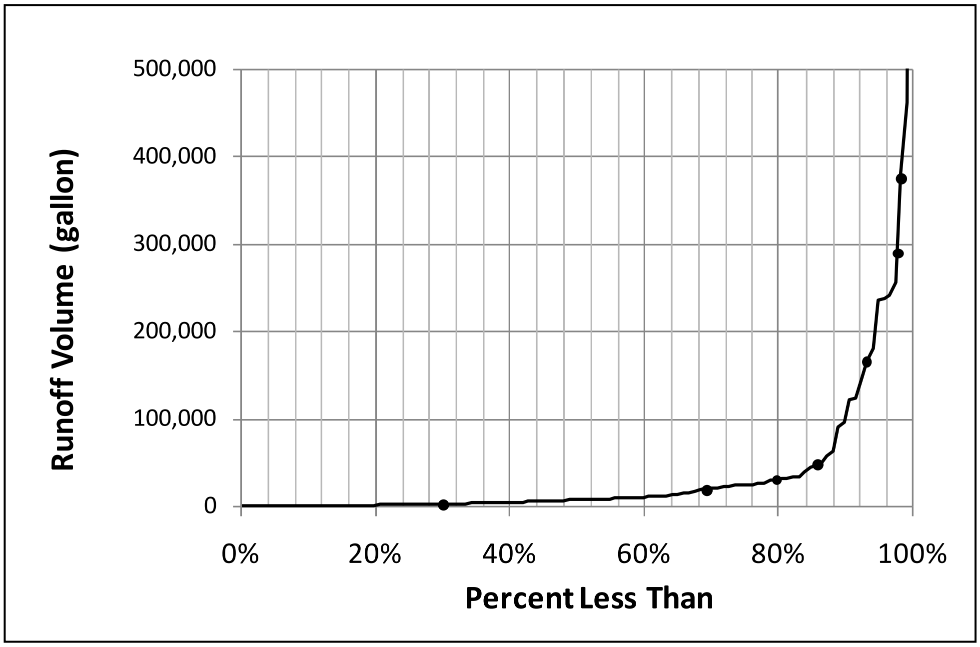

Figure 13 - Parkway cumulative runoff distribution showing monitored storm events

Pollutant Removal Summary

Event Mean Concentrations (Water Column)

Discussion in the section is limited to water column concentrations. Water column mass removals are discussed in the next section. Average EMC reduction performance of the four baffle boxes are summarized in Tables 9 through 12. An example regression of TSS discharge EMC to influent EMC is shown in Fig. 15 for the Rockledge baffle box (n=7). The correlation had an R^2 of 0.72. Average EMC reductions represent the average percent reduction in EMC based on the monitored storm events. The overall flow weighted mass removal efficiency (last column on Tables 9-12) accounts for the masses removed during the storm events. EMC performance of the four baffle boxes are compared in Table 14. Overall EMC reduction efficiency was moderate or negative for suspended solids, total nitrogen, and total phosphorus. EMCs were used for the water column mass calculations in the next section.

There was not a strong correlation between TN, TP, and fecal coliform effluent concentrations. Type 1 baffle boxes averaged a 46.9% increase between influent and effluent fecal coliform concentrations. Type 2 baffle boxes had mixed results with a 13.1% reduction at the Sarasota site and -249% increase in fecal coliform concentrations at the Rockledge site. See Table 13. Probable causes for fecal coliform growth in baffle boxes are the interevent anaerobic conditions discussed further in the Interevent Monitoring section.

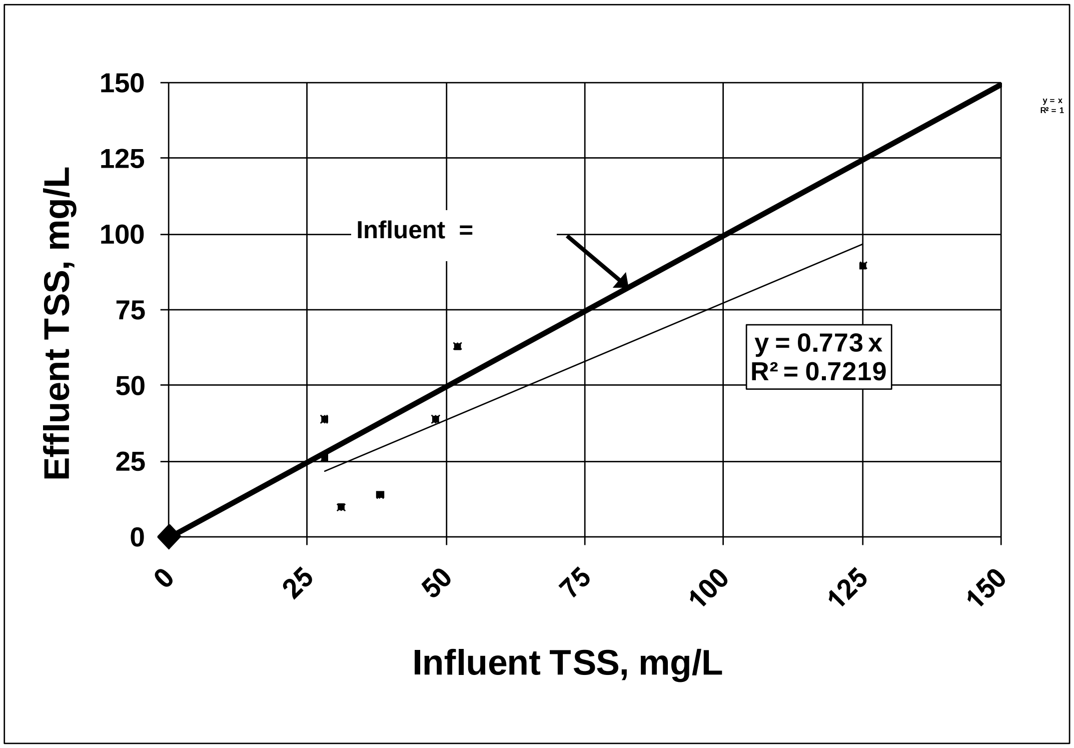

Figure 14 - Regression of Total Suspended Solids EMCs at Rockledge

Constituent	Average EMC_{inf}	Average EMC_{eff}	Average % EMC Reduction	EMC % Reduction Range		Average EMC Reduction, (EMC_{inf}-EMC_{eff})	Flow Weighted Mass Removal Efficiency, %
				Minimum	Maximum		
Total Suspended Solids, mg/L	49.0	43.2	8.5	-57	68	5.7	8.5
Total Nitrogen, mg/L	2.19	2.14	-11.3	-67	36	0.05	-4.3
Total Kjeldahl Nitrogen, mg/L	1.75	1.85	-17.3	-77	19	-0.10	-14.8
Organic Nitrogen, mg/L	1.56	1.62	-15.2	-71	24	-0.06	-14.4
NH_4^+-N, mg/L	0.19	0.22	-31.6	-157	72	-0.04	-18.5
NO_x-N, mg/L	0.45	0.30	10.2	-18	68	0.15	37.2
Total Phosphorus, mg/L	0.56	0.57	-8.2	-27	18	-0.01	-2.9
Organic Phosphorus, mg/L	0.23	0.23	-4.7	-27	17	-0.003	-1.6
PO_4-P, mg/L	0.33	0.34	-13.3	-57	18	-0.01	-4.0
Fecal Coliform, counts/100 ml	34,517	78,014	-249	-841	75	0.10000	-28.3
Cadmium, ug/L	0.00085	0.00059	9.4	0	47	-0.08200	36.3
Chromium, ug/L	0.00321	0.00293	9.5	-28	34	-0.02000	-0.7
Copper, ug/L	0.00773	0.00768	0.014	-34	56	0.00000	-7.1
Zinc, ug/L	0.07523	0.06315	5.1	-136	35	0.00000	14.6

Table 9 - Rockledge baffle box EMC performance

Constituent	Average EMC_{inf}	Average EMC_{eff}	Average % EMC Reduction	EMC % Reduction Range		Average EMC Reduction, (EMC_{inf}-EMC_{eff})	Flow Weighted Mass Removal Efficiency, %
				Minimum	Maximum		
Total Suspended Solids, mg/L	108.4	66.5	35.1	-65	89	41.9	49.7
Total Nitrogen, mg/L	3.62	2.42	30.6	14	52	1.20	41.2
Total Kjeldahl Nitrogen, mg/L	3.48	2.27	32.5	15	52	1.22	42.5
Organic Nitrogen, mg/L	3.26	2.12	31.8	15	52	1.14	42.8
NH_4^+-N, mg/L	0.22	0.15	20.7	-84	78	0.07	33.4
NO_x-N, mg/L	0.13	0.15	-95.3	-500	12	-0.02	-35.5
Total Phosphorus, mg/L	0.59	0.44	21.6	-3	59	0.15	39.5
Organic Phosphorus, mg/L	0.34	0.22	37.7	-18	98	0.123	43.8
PO_4-P, mg/L	0.25	0.22	7.6	-17	67	0.02	32.1
Fecal Coliform, counts/100 ml	74,250	40,250	13	-19	25	0.20900	57.3
Chromium, ug/L	0.00000	0.00000	0.0	-396	66	-0.04300	Cr
Copper, ug/L	0.00000	0.00000	0.000	-480	96	0.00500	Cu
Zinc, ug/L	0.00000	0.00000	0.0	-93	109	0.00000	Zn

Table 10 - Sarasota baffle box EMC performance

Constituent	Average EMC_{inf}	Average EMC_{eff}	Average % EMC Reduction	EMC % Reduction Range		Average EMC Reduction, (EMC_{inf}-EMC_{eff})	Flow Weighted Mass Removal Efficiency, %
				Minimum	Maximum		
Total Suspended Solids, mg/L	55.8	35.5	12.3	-61	78	20.3	41.3
Total Nitrogen, mg/L	1.00	0.97	-8.3	-45	65	0.03	11.1
Total Kjeldahl Nitrogen, mg/L	0.81	0.73	-5.5	-49	67	0.08	17.6
Organic Nitrogen, mg/L	0.72	0.65	-7.6	-49	65	0.07	16.0
NH_4^+-N, mg/L	0.10	0.08	8.3	-51	87	0.02	29.0
NO_x-N, mg/L	0.19	0.24	-50.7	-373	17	-0.05	-16.8
Total Phosphorus, mg/L	0.17	0.15	1.5	-20	58	0.02	12.8
Organic Phosphorus, mg/L	0.13	0.12	-1.1	-26	62	0.011	12.5
PO_4-P, mg/L	0.04	0.03	5.4	-44	36	0.00	14.0
Fecal Coliform, counts/100 ml	5,088	10,505	-89	-600	75	0.01690	-32.4
Cadmium, ug/L	0.00066	0.00063	9.4	0	49	-0.01100	6.9
Chromium, ug/L	0.00311	0.00308	-13.4	-75	73	0.00200	12.2
Copper, ug/L	0.01309	0.01168	7.612	-50	75	0.00000	24.0
Zinc, ug/L	0.13700	0.08084	18.7	-28	129	0.00000	38.9

Table 11 - Lincoln baffle box EMC performance

Constituent	Average EMC_{inf}	Average EMC_{eff}	Average % EMC Reduction	EMC % Reduction Range		Average EMC Reduction, (EMC_{inf}-EMC_{eff})	Flow Weighted Mass Removal Efficiency, %
				Minimum	Maximum		
Total Suspended Solids, mg/L	39.5	45.7	-38.5	-122	4	-6.2	-5.6
Total Nitrogen, mg/L	2.48	2.14	5.6	-53	52	0.35	14.1
Total Kjeldahl Nitrogen, mg/L	1.94	1.69	4.1	-48	55	0.25	11.6
Organic Nitrogen, mg/L	1.80	1.57	3.1	-61	56	0.24	11.9
NH_4^+-N, mg/L	0.14	0.12	-112.8	-882	65	0.02	5.7
NO_x-N, mg/L	0.54	0.45	2.7	-59	43	0.09	23.2
Total Phosphorus, mg/L	0.51	0.56	-15.3	-90	18	-0.05	-8.0
Organic Phosphorus, mg/L	0.12	0.15	-20.1	-65	51	-0.028	-49.5
PO_4-P, mg/L	0.39	0.41	-21.1	-181	9	-0.02	5.6
Fecal Coliform, counts/100 ml	37,736	61,419	-4	42	40	0.06000	-5.9
Cadmium, ug/L	0.00044	0.00041	-3.8	-100	28	-0.29000	24.4
Chromium, ug/L	0.00259	0.00246	5.5	-7	8	0.01200	5.5
Copper, ug/L	0.00793	0.00809	-19.538	-125	53	0.00000	5.3
Zinc, ug/L	0.04267	0.04583	-19.0	-233	3	0.00000	3.3

Table 12 - Parkway baffle box EMC Performance

Site	Baffle Box Type	Average TN Effluent Conc. (mg/L)	Average TP Effluent Conc. (mg/L)	Average Fecal Coliform Effluent Concentration (counts/100mL)
Parkway Blvd, Stuart	1	2.14	0.56	61,419
Lincoln Lane, Stuart	1	0.97	0.15	10,505
Average Type 1		**1.56**	**0.36**	**35,962**
Little John Lane, Rockledge	2	2.14	0.57	78,014
Oriole Drive, Sarasota	2	2.42	0.44	40,250
Average Type 2		**2.18**	**0.51**	**59,132**

Table 13 - Summary pollutant concentrations for all four baffle boxes

Site	Average EMC Removal Efficiency, %			
	Total suspended solids	Total nitrogen	Total phosphorus	Fecal coliforms
Little John Drive, Rockledge City	8.5	-11.3	-8.2	-249
Oriole Drive, Sarasota	35.1	30.6	21.6	13.1
Lincoln Avenue, Stuart City	12.3	-8.3	1.5	-89.5
SE Parkway Drive, Stuart City	-38.5	5.6	-15.3	-4.2
Average	4.4	4.2	-0.1	-82.4

Table 14 - Comparison of average baffle box EMC performance

Mass in Water Column, Bottom Chamber and Sieve Screen

The masses of constituents contained in the solids that accumulated in the bottom chambers and sieve screens are summarized in Tables 15 through 18 respectively for the Rockledge, Sarasota, Lincoln, and Parkway baffle boxes. Also shown is the calculated mass removed in the water column based on EMC monitoring discussed in the previous section. The ratio of the total accumulated solids mass to calculated water column mass scales the mass calculations.

In the material collected from the Rockledge sieve screen, the mass of non-dissolved solids, TN, and TP in the < 1 mm fraction were greater than or similar to the > 1 mm fraction. The solids in the < 1 mm fraction were a combination of sediment, and fine organic debris. The % organic matter in the Rockledge > 1 mm fraction were 73.3 and 11% for Cleanouts 1 and 2, and for the < 1 mm fraction were 30 and 51.6%.

For the Sarasota baffle box, the % organic matter in the > 1 mm fraction was 83% and for the < 1 mm fraction was 54.6%. For the Rockledge baffle box, accumulated solids are 26.8 times the water column EMC calculation, indicating that the autosampler is not representing all stormwater solids in the stormwater entering the baffle box. Negative values for nitrogen and phosphorus indicate that these parameters were actually being exported during storm events. Variable results for other baffles boxes reflect the flow and quality characteristics of runoff, limited solids mass that accumulate within the baffle box, and uncertainties in sampling, analysis and quantification of solid materials that accumulate within the baffle box.

Constituent	Bottom Chambers	Strainer Screen		Total Chamber + Screen	Water Column	Water Column Mass/ Accumated Solids Mass
		> 1 mm	< 1 mm			
Non-dissolved Solids	3,479	1,012	1,378	5,869	110	0.019
Total Nitrogen	16.1	0.79	1.14	17.99	-1.91	-0.106
Total Phosphorus	1.1	0.64	1.05	2.80	-0.32	-0.116

Table 15 - Rockledge baffle box constituent mass (lb)

Constituent	Bottom Chambers	Strainer Screen		Total Chamber + Screen	Water Column	Water Column Mass/ Accumated Solids Mass
		> 1 mm	< 1 mm			
Non-dissolved Solids	1627	2491	3586	7704	7232	0.94
Total Nitrogen	9.0	1.64	21	32	200	6.3
Total Phosphorus	1.4	0.26	4.20	5.81	29	5.0

Table 16 - Sarasota baffle box constituent mass (lb)

Constituent	Bottom Chambers	Water Column	Water Column Mass/ Accumated Solids Mass
Non-dissolved Solids	3,014	3,521	1.17
Total Nitrogen	1.28	16.0	12.5
Total Phosphorus	1.05	3.28	3.13

Table 17 - Lincoln baffle box constituent mass (lb)

Constituent	Bottom Chambers	Water Column	Water Column Mass/ Accumated Solids Mass
Non-dissolved Solids	87	-195	-2.2
Total Nitrogen	0.030	19.1	628
Total Phosphorus	0.017	-1.95	-116

Table 18 - Parkway baffle box constituent mass (lb)

Average Parameter Mass Removals Over Monitoring Period	Type 1 Baffle Box	Type 2 Baffle Box
TN Removed From Water Column (lb)	35.1	198.1
TN Removed From Vault (lb)	1.31	25.1
TN Removed From Screens (lb)	NA	24.57
TP Removed From Water Column (lb)	1.33	28.68
TP Removed From Vault (lb)	1.07	2.5
TP Removed From Screens (lb)	NA	6.15

Table 19 - Summary mass removals by baffle box type

Equivalent Concentrations

Equivalent concentrations based on treatment volume and mass removals from the whole study period are shown in Table 20 for solids, nitrogen and phosphorus. ECs were higher for the Type 2 baffle box that included the sieve screen, but the higher EC in Type 2 baffle boxes also reflected the characteristics of the contributing watershed. The contributing watersheds to the Type 2 baffle boxes (Rockledge and Sarasota) had large macroscopic vegetation inputs and limited upstream opportunity for attenuation of pollutant mass. The Stuart sites had relatively limited organic matter input and possible upstream attenuation.

Site	Equivalent Concentration of Accumulated Solids (mg/L)		
	Total non-dissolved solids	Total nitrogen	Total phosphorus
Little John Drive, Rockledge City	183	0.69	0.071
Oriole Drive, Sarasota	37.9	0.098	0.015
Lincoln Avenue, Stuart City	20.2	0.009	0.007
SE Parkway Drive, Stuart City	1.8	0.00063	0.00035
Average	60.7	0.20	0.023

Table 20 - Equivalent concentrations of accumulated solids

Derived Efficiencies

Derived Efficiencies based on total mass removals are summarized in Table 1. DE for Type 1 baffle boxes averaged 0.5% for nitrogen and 2.3% for phosphorus. Type 2 baffle boxes averaged 19.1% DE for TN and 15.5% DE for TP. The higher removal efficiencies of Type 2 baffle boxes was attributed to the sieve screen capture of large floating and suspended materials in Type 2 boxes. Note that mass loadings from leaves were in drainage basins having 44% to 87% tree canopy coverage.

Site	Baffle Box Type	TN Mass Removal Efficiency (%)	TP Mass Removal Efficiency (%)	TN EMC Removal Efficiency (%)	TP EMC Removal Efficiency (%)
Parkway Blvd, Stuart	1	0.03	0.06	5.60	-15.30
Lincoln Lane, Stuart	1	1.00	4.50	-8.30	1.50
Average Type 1		**0.50**	**2.30**	**-1.35**	**-6.90**
Little John Lane, Rockledge	2	28.10	19.40	-11.30	-8.20
Oriole Drive, Sarasota	2	10.00	11.60	30.60	21.60
Average Type 2		**19.05**	**15.50**	**9.65**	**6.70**

Table 21 - Mass removal efficiencies of monitored baffle boxes

Polycylycic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbon (PAH) concentrations in accumulated solids are shown in Figures 16 through 19. PAH levels in bottom chamber and sieve screen solids are summarized in Tables 22 and 23 based respectively on total dry solids and solid organic matter. For the Rockledge baffle box, PAH levels were highest in the sieve screen captured material that was smaller than 1 mm, and both size fractions of the sieve screen material had higher PAH levels than the chamber sediment (Fig. 16). The PAH levels were below the exposure limits found in Chapter 62-777, Table II, F.A.C., with the exception of Benzo (A) pyrene, which was slightly higher than residential and industrial exposure limits.

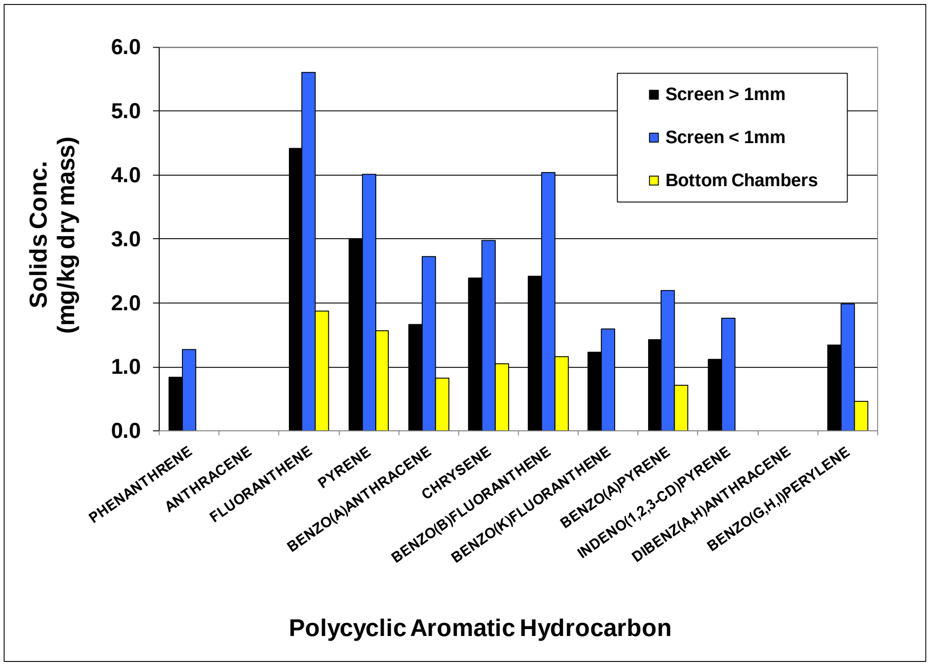

Figure 15 – Polycyclic aromatic hydrocarbons in Rockledge solids

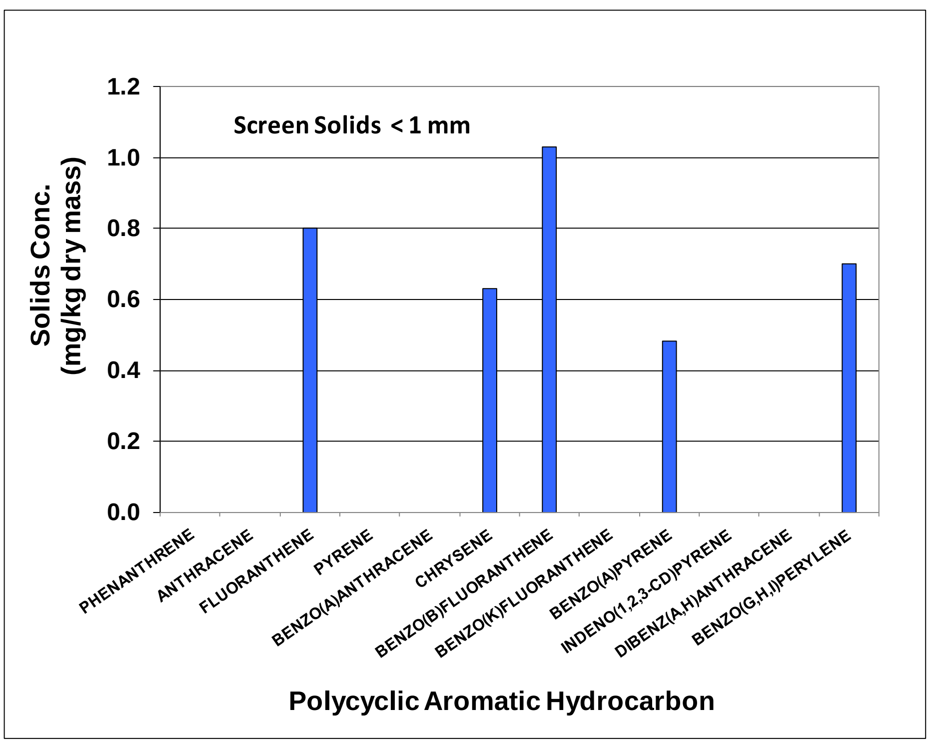

Figure 16 - Polycyclic aromatic hydrocarbons in Sarasota solids (bottom chamber PAH reported as less than detection limit)

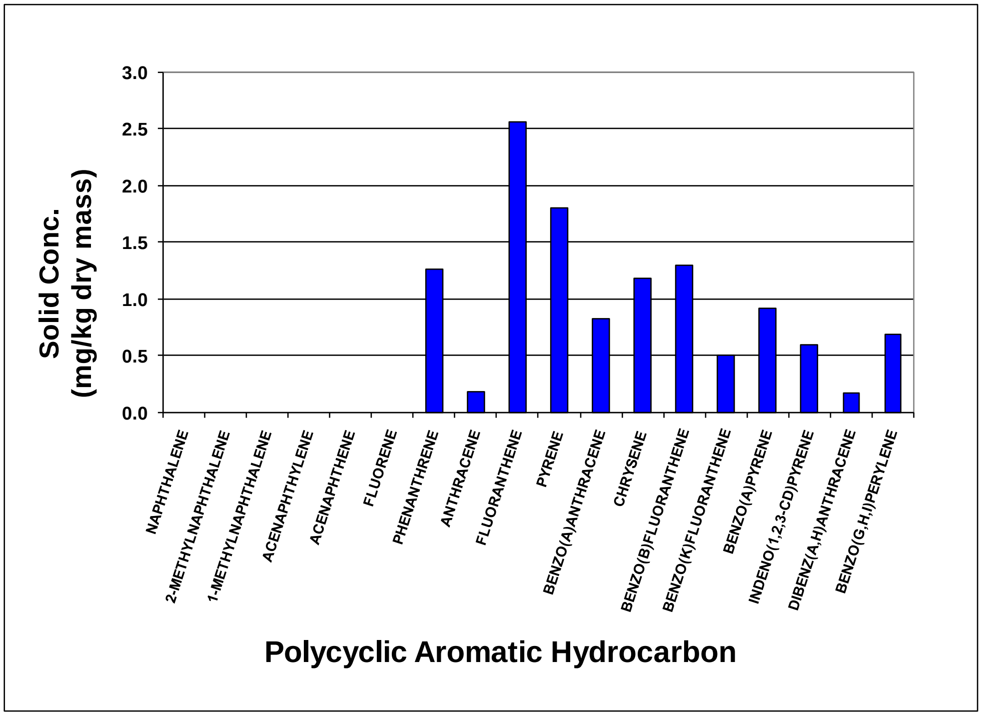

Figure 17 - Polycyclic aromatic hydrocarbons in Lincoln solids.

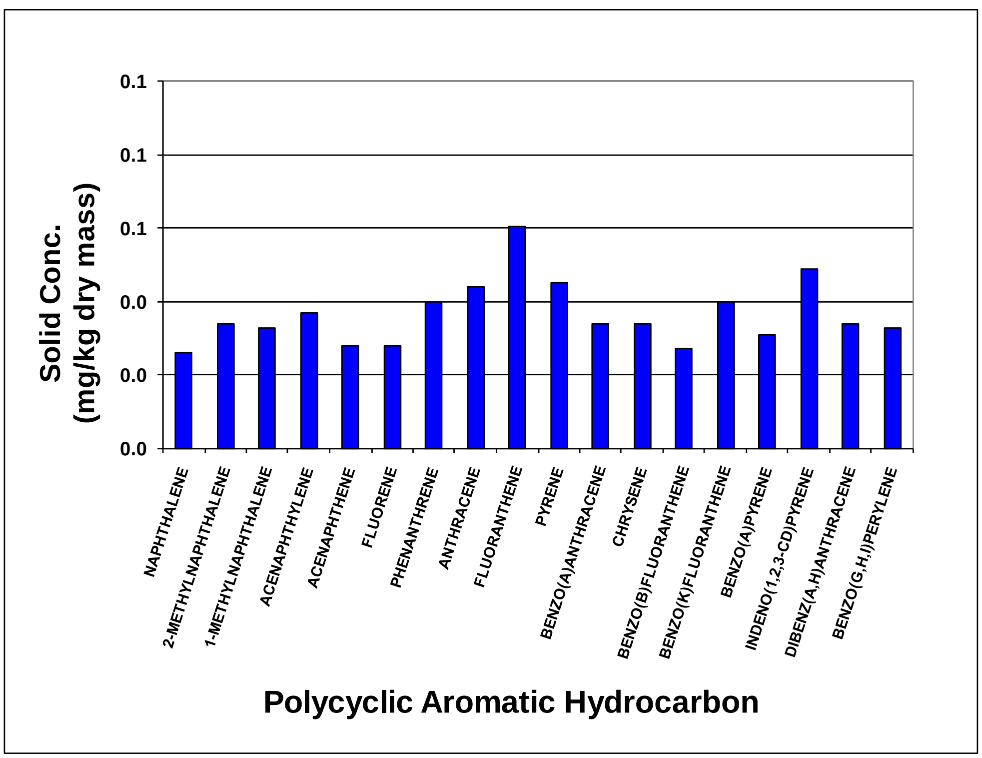

Figure 18 - Polycyclic aromatic hydrocarbons in Parkway solids.

Site	Total PAH, mg/kg solids		
	Bottom chamber	Sieve screen > 1 mm	Sieve screen < 1 mm
Little John Drive, Rockledge City First Cleanout	7.6	19.8	28.2
Little John Drive, Rockledge City Second Cleanout	1.7	52.9	70.0
Oriole Drive, Sarasota	ND	ND	3.02
Lincoln Avenue, Stuart City First Cleanout	12.0	-	-
Lincoln Avenue, Stuart City Second Cleanout	15.5	-	-
SE Parkway Drive, Stuart City	0.66	-	-

Table 22 - Total polycyclic aromatic hydrocarbons in accumulated solids

Site	Total PAH, mg/kg solid organic matter		
	Bottom chamber	Sieve screen > 1 mm	Sieve screen < 1 mm
Little John Drive, Rockledge City First Cleanout	60.7	27.1	94.0
Little John Drive, Rockledge City Second Cleanout	10.0	480.9	135.6
Oriole Drive, Sarasota	5.52	ND	ND
Lincoln Avenue, Stuart City First Cleanout	29.1	-	-
Lincoln Avenue, Stuart City Second Cleanout	266	-	-
SE Parkway Drive, Stuart City	6.3	-	-

Table 23 - Organic carbon normalized total polycyclic aromatic hydrocarbons levels

Heavy Metals

The reported levels of heavy metals in solids materials from sieve screen and bottom chamber are listed below.

Metal	Bottom Chamber Material, mg/kg dry weight		Sieve Screen Material, mg/kg dry weight			
	Cleanout 1	Cleanout 2	Cleanout 1		Cleanout 2	
			> 1 mm	< 1 mm	> 1 mm	< 1 mm
Cadmium	0.0404	2.10	0.643	0.471	0.73	0.70
Chromium	4.6	29	449	18.1	10	9.6
Copper	8.17	15.6	41.9	36	12	9.02
Nickel	1.59	14	5.9	4.59	4.8	6.57
Zinc	58.5	49.8	213	184	59.8	48.9
Mercury	0.0162	0.009	0.0783	0.0909	0.042	0.030

Table 24 - Metals concentration in Rockledge water column and solids

Metal	Bottom Chamber Material, mg/kg dry weight	Sieve Screen Material, mg/kg dry weight	
		> 1 mm	< 1 mm
Cadmium	0.55	0.14	0.68
Chromium	6.3	3.2	21.2
Copper	22.6	33.4	145
Nickel	2.9	1.6	8.5
Zinc	116	158	329
Mercury	-	0.028	0.142

Table 25 - Metals concentration in Sarasota water column and solids

Metal	Bottom Chamber Material, mg/kg dry weight	
	Cleanout 1	Cleanout 2
Cadmium	0.144	0.95
Chromium	5.5	13
Copper	19.4	8.4
Nickel	2.03	6.2
Zinc	290	108
Mercury	0.0158	0.0051

Table 26 - Metals concentration in Lincoln water column and solids

Metal	Bottom Chamber Material, mg/kg dry weight
	Cleanout 1
Cadmium	0.87
Chromium	12.0
Copper	2.8
Nickel	5.70
Zinc	44
Mercury	0.0060

Table 27 - Metals concentration in Parkway water column and solids

Interevent Monitoring

A primary mechanism by which baffle boxes remove stormwater pollutants is by sedimentation of stormwater solids that enter during storm events, sieving in Type 2 baffle boxes, and by retention of large macroscopic solids that may bypass the sieve screen and become trapped beneath it and ultimately sink to the bottom. In interevent periods, the organic materials in the solids that collect in bottom chambers can biologically degrade. Organic matter degradation could be expected to result in oxygen utilization with possible anoxic or anaerobic conditions and release of inorganic nutrients from the decomposing solids. Inorganic nutrients in the baffle box water column could be flushing into the receiving water during the initial period of the next storm event, or continuously flushed out if there was a baseflow during interevent periods. A limited scope sampling program was implemented as a first step in assessing interevent water quality within baffle boxes. Another scope task was to evaluate methods of collection and laboratory analyses for the materials that accumulate in the sieve screens of Type 2 baffle boxes. This material is a mixture of large size vegetation (leaves, plant parts), smaller organic materials, and inorganic particles. The estimate of the mass of pollutant removed in solids that accumulated within sieve screens depends on the sampling, sample preparation, and analytical methods used to characterize these materials. Interevent monitoring and sampling of the four baffle boxes was conducted on 3/25/2009. Monitoring included measurements of dissolved oxygen profiles, point measurements of temperature, pH, alkalinity and oxidation reduction potential, and collection of water column samples from a single point in the downstream baffle box chamber for laboratory analyses of suspended solids, BOD, COD, and nitrogen and phosphorus species. Water column samples were stored on ice and delivered to Pace Analytical Services, Inc. Tampa, FL on 3/26/2009.

Dissolved oxygen profiles are shown in Figure 20. Dissolved oxygen in the Rockledge and Sarasota baffle boxes was zero from 6 in. below the surface to the bottom. The Lincoln and Parkway baffle boxes had DO greater than 4 throughout their depth. For all baffle boxes, DO levels were constant through the vertical profile of the baffle boxes, with very limited depth stratification. Water column field parameter results for the interevent monitoring are summarized in Table 28. The water quality of the Type 2 baffle boxes (Rockledge and Sarasota) was distinct from the Type 1 baffle boxes (Lincoln and Parkway). Rockledge and Sarasota exhibited zero dissolved oxygen, highly negative oxidation reduction potentials, and higher chemical and biochemical oxygen demand, total nitrogen, and total phosphorus. Highly negative oxidation reduction potentials indicate that oxygen has been consumed and reducing conditions have been established by biochemical degradation of organic matter.

These observations are consistent with the hypothesis that organic matter captured in the Rockledge and Sarasota baffle boxes undergoes biological decomposition within the baffle box, leading to depletion of molecular oxygen, anaerobic redox conditions, and release of inorganic and soluble nutrient species into the overlying water column within the baffle box. The data in Figure 20 provide the first known documentation of patterns of DO depletion in Florida baffle boxes, due ostensibly to interevent biochemical processes. Organic matter decomposition was apparently more significant in the Rockledge and Sarasota baffle boxes, while the Lincoln and Parkway baffle box DO and ORP indicated a lower predominance of organic matter decomposition. Several factors could contribute to the observed difference in the interevent water quality between the Type 2 and Type 1 baffle boxes. The most significant could be the characteristics of the contributing watershed, particularly in terms of the vegetative contributions from the watershed. Rockledge and Sarasota watersheds were generally highly vegetated while vegetation coverage in the Lincoln and Parkway watersheds was much lighter.

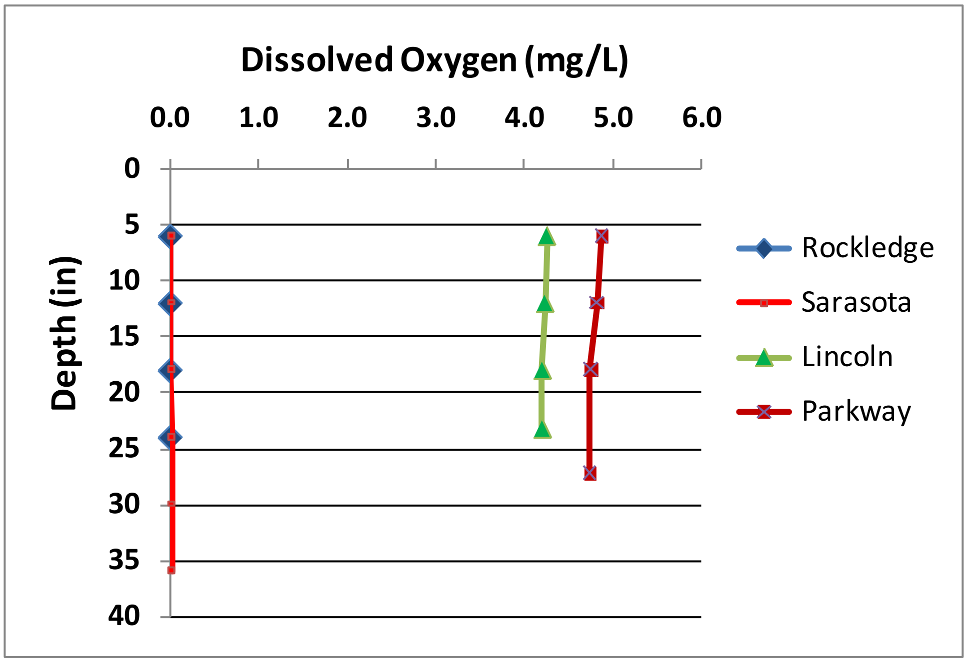

Figure 19 – Dissolved oxygen profiles in baffle boxes

The organic matter and vegetation that are subject to biological decomposition in a Type 2 baffle box can include materials that are retained in the sieve screen overlying the water column and materials that are not retained in the sieve screen that end up in the bottom chambers. Organic particulate material can enter the bottom chamber through bypass of the sieve screen or by transport of smaller organic matter through the sieve screen itself, particularly when the screen has been cleaned and a mat layer has not built up. Storm-transported vegetation that enters a Type 1 baffle box could pass directly through the baffle box into the receiving water, thus not contributing to water quality modifications in the baffle box itself. Another factor is the contribution of baseflow, which could act to continuously dilute soluble nutrients releases from decaying organic matter.

The second interevent monitoring task was to collect solid materials that accumulated in the sieve screens of the Type 2 baffle boxes (Rockledge and Sarasota) and to provide subsample splits to different laboratories for nitrogen and phosphorus analyses using wet chemistry and composting analytical methods. Three separate samples of solid material accumulated in the

Rockledge sieve screens were collected. Each sample was subdivided into three subsamples, which were shipped to three separate laboratories for analyses. The three laboratories that received solid material subsamples were A&L Great Lakes Laboratories, Inc. **(A&L)**, Ft. Wayne, IN (water and compost methods); Columbia Analytical Services, Inc. **(Columbia)**, Jacksonville, FL (water methods); and the Institute of Food and Agricultural Sciences Analytical Services Laboratories **(IFAS),** Environmental Water Quality Laboratory, University of Florida, Gainesville, FL (water methods).

A primary question investigated was the appropriateness of using water and wastewater test methods for the sediments and biosolids captured in the baffle box screens and chambers. An alternative to water based methods was to use analytical methods from the solid waste and agricultural industries. A&L used test procedures from Standard Methods for the Examination of Water and Wastewater and Test Methods for Evaluating Solid Waste, Physical/Chemical Methods (Table 29). In addition, A&L used Test Methods for the Examination of Composting and Compost, as shown in Table 30. Columbia used Methods of Chemical Analysis of Water and Waste analytical procedures.

On the sample date the sieve screen in the Sarasota baffle box contained negligible quantities of solid material so sample collection was not possible. The Rockledge sieve screen materials contained highly visible macroscopic plant matter and also small organic and non-organic sediment material.

Parameter	Rockledge	Sarasota	Lincoln	Parkway
Time	1300	1700	0730	0930
Temperature, C	19.4	21.40	21.5	21.70
pH	6.8	7.0	7.1	7.5
Alkalinity, mg/L as $CaCO_3$	73	144	44	125
Dissolved Oxygen, mg/L	0	0	4.2	4.8
ORP, mV	-306	-357	117	138
Total suspended solids, mg/L	8.5	8.3	12	5.0
Carboneceous biochemical oxygen demand, five day, mg/L	10	28	2.0	2.0
Chemical oxygen demand, mg/L	91	120	31	22
Total nitrogen, mg/L	0.03	0.03	0.10	0.97
Total kjeldahl nitrogen, mg/L	2.2	3.9	0.95	0.65
Organic nitrogen, mg/L	-0.25	-1.20	-0.14	-0.02
Ammonia nitrogen, mg/L	.25	1.20	0.14	0.02
(Nitrate+nitrite) nitrogen, mg/L	0.03	0.03	0.10	0.97
Total phosphorus, mg/L	.89	1.40	0.13	0.57
Organic phosphorus, mg/L	0.29	0.30	0.10	0.07
Orthophosphorus, mg/L	0.60	1.1	0.029	0.50

Table 28 - Average water column values of field parameters

Results of analyses of the solid materials removed from the Rockledge sieve screen are presented in Tables 29 and 30. Analytical results were provided by two laboratories (A & D and Columbia). The third laboratory (IFAS) was in possession of the samples for over four months and finally reported that nutrient analyses could not be performed due to the unique characteristics of the sample matrix and technical issues associated with sample processing.

Note that A&L used a volatile solids method to estimate organic matter in the solids while Columbia used a total organic carbon analysis.

For the same reported analyte, the percent error between A&L and Columbia results was calculated as the absolute difference in the reported A&L and Columbia results divided by the absolute value of the A&L result, multiplied by 100 (Table 29). For wet chemistry analyses, the average percent error in the total solids analyses reported by the two laboratories was 0.73% (n=3) with a range of -13.2 to +7.4%. For total kjeldahl nitrogen, the average percent error was +14.5% (n=3) and with a range of -1.8 to +48.4%. TKN results in Columbia Subsample 1 was particularly lower than other TKN values and was likely due to difficulties in processing of the subsample prior to digestion. The average percent error for total phosphorus was +29.3% (n=3) and with a range of +26.3 to +33.8%. The variation in the two reported results was significant for both nitrogen and phosphorus. The different results could have a significant effect on calculations of nutrient removal in the material captured on sieve screens of Type 2 baffle boxes. Inspection of the water method results for TP (Table 29) indicates that results were relatively consistent among the three subsamples for both A&L (mean = 1500, range = 1481 to 1524) and Columbia (mean = 1060, range = 980 to 1100). Mean TP reported by A&L was 41% higher than Columbia, however, indicating that interlaboratory variability for these types of samples can be significant.

Sample	Parameter	A&L	Columbia	A&L Method	Columbia Method	Percent Error[1]
1	Total Solids, %	24.84	23	SM (20th) 2540G	160.3MOD	7.4
	Volatile Solids, %	89	-	SM (20th) 2540G	-	-
	Total Kjeldahl Nitrogen, mg/kg	16,659	8,600	SM-4500 N(org)B & NH	351.2	48.4
	Total Phosphorus, mg/kg	1,481	980	SW846-6010B	365.1	33.8
	Total organic carbon, mg/kg	-	10,000	-	9060M	-
2	Total Solids, %	19.42	22	SM (20th) 2540G	160.3MOD	-13.3
	Volatile Solids, %	90	-	SM (20th) 2540G	-	-
	Total Kjeldahl Nitrogen, mg/kg	17,482	18,000	SM-4500 N(org)B & NH	351.2	-3.0
	Total Phosphorus, mg/kg	1,524	1,100	SW846-6010B	365.1	27.8
	Total organic carbon, mg/kg	-	15,000	-	9060M	-
3	Total Solids, %	20.67	19	SM (20th) 2540G	160.3MOD	8.1
	Volatile Solids, %	89	-	SM (20th) 2540G	-	-
	Total Kjeldahl Nitrogen, mg/kg	18,670	19,000	SM-4500 N(org)B & NH	351.2	-1.8
	Total Phosphorus, mg/kg	1,495	1,100	SW846-6010B	365.1	26.4
	Total organic carbon, mg/kg	-	11,000	-	9060M	-

[1] (A&L Result - Columbia Result)/A&L Result x 100

Table 29 - Water analyses method results for Rockledge sieve screen subsamples

Table 30 shows analytical results that were obtained for the three subsamples using Test Methods for Evaluation of Compost and Composting (TMECC) analytical procedures performed by A& L Laboratories. TMECC results were compared to A&L water analyses results by making appropriate unit conversions to compare water analysis results with TMECC results. TMECC % Organic Matter was 72 to 95% (mean = 83%) of water analysis volatile solids. TMECC % Total Nitrogen was 93 to 118% (mean = 112%) of water analysis Total Kjeldahl Nitrogen. TMECC % Total Phosphorus was 97 to 109% (mean = 102%) of water analysis Total Phosphorus. These results suggest that TMECC composting analytical methods may be applicable to analyses of sieve screen material analyses. Further work is required to verify this result and gain confidence in the methods. The units for water column methods are expressed in solids concentrations of mg/kg, while solids methods units are given as "percent" of a parameter. The differences in units between the two methods explains why there are blank values in Table 29. The appropriateness of using calculations that combine water based analytical methods and units from the water column with solids based analytical methods and units for gross solids is uncertain.

Sample	Parameter	A&L	Method
1	Total Nitrogen, %	0.49	TMECC 04.02-D
	Total Phosphorus, %	0.04	TMECC 04.03-A
	Organic matter by LOI @ 550C, %	15.87	TMECC 05.07-A
2	Total Nitrogen, %	0.42	TMECC 04.02-D
	Total Phosphorus, %	0.03	TMECC 04.03-A
	Organic matter by LOI @ 550C, %	14.35	TMECC 05.07-A
3	Total Nitrogen, %	0.36	TMECC 04.02-D
	Total Phosphorus, %	0.03	TMECC 04.03-A
	Organic matter by LOI @ 550C, %	17.62	TMECC 05.07-A

Table 30 - Compost analyses method results for Rockledge sieve screen subsamples

Additional sampling was conducted on 10/5/2009. Three samples were collected of materials that had accumulated in the sieve screen of the Sarasota baffle box. Samples were shipped to the Columbia Analytical Laboratory for analyses of total solids, TKN, and TP. Results are shown in Table 31. Mean parameter values for TS, TKN, and TP were 26.7%, 11,767 mg/kg and 1006 mg/kg, respectively. The coefficient of variation for the three TS, TKN and TP samples were 0.13, 0.20 and 0.25, which indicates that the results were reasonable similar for the three samples. TKN from the Sarasota sieve screen material was generally about two thirds that of the material collected from the Rockledge sieve screen, while Sarasota TP was to 67 to 95 % of the Rockledge TP depending on which laboratory data for Rockledge TP are used for comparison.

Sample	Parameter	Columbia	Columbia Method
1	Total Solids, %	30	160.3MOD
	Total Kjeldahl Nitrogen, mg/kg	12,000	351.2
	Total Phosphorus, mg/kg	860	365.1
2	Total Solids, %	27	160.3MOD
	Total Kjeldahl Nitrogen, mg/kg	9,300	351.2
	Total Phosphorus, mg/kg	860	365.1
3	Total Solids, %	23	160.3MOD
	Total Kjeldahl Nitrogen, mg/kg	14,000	351.2
	Total Phosphorus, mg/kg	1,300	365.1

Table 31 - Water analyses method results for Sarasota sieve screen samples

The results of the sieve screen analyses were mixed overall, with some consistent results and some inconsistencies. Five of the six Rockledge TKN were in reasonable agreement with each other; one TKN was significantly different from the two other TKN from the same lab and also significantly different from the subsamples supplied to the second lab. Rockledge TP values were in reasonable agreement for three samples for each lab, but consistently different between labs. Sample processing methodology may have had some influence on the discrepancy. Unfortunately, the third laboratory had reservations about a methodology and elected not to pursue analyses. Significant differences between Rockledge and Sarasota TKN and TP could reflect differences in the materials captured within the sieve screens and transformations of materials that occur in the captured material. For both nitrogen and phosphorus, reported nutrient values of sieve screen materials were subject to large differences for the small number of split samples analyzed. This result was not unexpected; it reaffirms the complexity of stormwater solids matrices and the need to focus more effort on them. A result which is encouraging is the relative agreement of total solids values for the two laboratories and the agreement of the composting methods for solids, nitrogen and phosphorus. The later suggests that composting or whole sample combustion methodologies, which do not employ sample digestion procedures, might be used in a standardized methodology for characterization of stormwater gross solids.

The scope of the interevent monitoring for sieve screen materials was highly limited due to budget restrictions. For analyses of solids collected in baffle boxes, and more generally for solid materials that are removed from stormwater management systems in Florida, a more comprehensive effort is needed to fully address the integrated tasks of collection, preparation, and analyses of solid materials captured in sieve screens and bottom sediments. The objective of this effort should be to develop a standardized protocol for sample collection, preservation, sample handling, and preparation, with the goal of providing protocols that can be applied with confidence by many entities and laboratories. The limited scope of the work provided valuable insight that can be used to formulate the needed methods development effort, which should as a minimum include a much greater number of split samples and analyses.

Conclusions and Recommendations

Total Maximum Daily Load (TMDL) mandates are challenging communities to reduce pollutants from stormwater runoff above and beyond standard permitting requirements associated with new development. The primary method used to reduce pollutants is by retrofitting older development with BMPs to clean runoff from those areas that do not have treatment practices. Retrofitting older areas with traditional treatment practices such as ponds is difficult due to lack of undeveloped land. The limited amount of undeveloped land in older developments turns stormwater practitioners to other tools in the BMP toolbox.

A common BMP used in ultra urban locations has been the baffle box. Early model (Type 1) baffle boxes were underground vault boxes with weirs set at the pipe inverts that trapped pollutants through the sedimentation unit process. The primary pollutants targeted by Type 1 baffle boxes were sediments, heavy metals, and PAHs associated with sediments that fell by gravity into water filled chambers. Removal of nutrient pollutants was minimal in Type 1 boxes.

Nutrient TMDLs are generally expressed as reductions of TN and TP. Nutrients can be found dissolved in the water column, bound to sediments, or part of the structural matrix of organic debris. The primary source of anthropogenic TN is dissolved fertilizer in the water column. A small amount of TN is associated with organic sediments. Organic debris leaches significant levels of TN and TP into water within 72 hours of submersion, England et.al. (2000). Approximately 30-40% of stormwater based TP is bound to sediment particles with the remainder being dissolved in the water column.

Development of TMDLs over the last few years has shown that nutrients were the primary pollutants causing environmental degradation in Florida. In response to the need to provide BMPs with nutrient removal capability, Suntree Technologies has developed proprietary Type 2 baffle boxes that added a horizontal screen above the water line of the vaults. This filtration unit process traps gross solids such as leaves, grass clippings, sediment, and trash during high flows when the hydraulic grade line rises above the screen level. After the water surface recedes upon cessation of rain, gross solids trapped in the screens are kept above the water filled vaults with the design goal of letting the organic debris dry to prevent leaching of nutrients into the vaults. In addition, the screens enhance sedimentation of organic and inorganic sediments by physically blocking and filtering particles that are limited to velocity constraints of Stokes law for settling in Type 1 baffle box designs. The unit processes of sedimentation and filtration in a baffle box do not provide treatment of water column based TN and TP.

Sarasota County received funding from FDEP to monitor two Type 1 and two Type 2 baffle boxes to document pollutant removal effectiveness, primarily focused on the parameters TN and TP. The County contracted with GPI-SE to develop and manage the monitoring program. Field monitoring and data collection was subcontracted to Sutron Corporation for three baffle boxes in Rockledge and Stuart, and to PBSJ for one baffle box in Sarasota.

BMP site selection is critical and challenging for an effective field monitoring program. Pollutant loadings vary with every watershed and every rainfall event. A site must be chosen that allows the researcher to control as many of the pollutant loading variables as possible. A site must allow for proper setup and maintenance of equipment and collection of samples. Recommendations for site selection to give an affective baffle box monitoring program are:

- Minimize equipment requirements by using a baffle box with one influent pipe and one effluent pipe, each of which uses one autosampler. Additional pipes will require additional autosamplers and flow meters. More equipment leads to more malfunctions and lost storm sampling opportunities.
- There should be no base flows through the pipes or backwater or submersion from downstream waterbodies.
- There should be no bypass flows during large storms.
- BMPs in roadways should not be monitored. Technician vehicles will need to be parked next to the site for sampling and equipment maintenance. Access dictates a location outside of the pavement for safety reasons and to avoid lane closures.
- For rain gauges and solar panels to operate accurately there can be no tree coverage over the site.
- Theft proof enclosures should be used to house autosamplers, batteries, and solar panels. Adjacent property owners should be canvassed to ensure their cooperation with technicians accessing equipment at any hour.
- Testing for gross solids requires selecting a watershed with a high tree canopy coverage.
- When monitoring to compare multiple BMPs, each BMP watershed should be of similar land use in order to have similar pollutant loadings for each BMP.
- The interior of the BMPs should have sufficient clearance and access to enable a technician to install equipment and take samples.
- The sites should be within reasonable driving distance of technicians who will be making weekly visits to inspect and calibrate equipment. Automated sampling equipment that contacts technicians via modem or internet should be used to minimize

site visits for rainfalls that do not trip the autosampler. Many storms in Florida are below tripping criteria for rain intensity and duration.
- Roadways in the watershed should have curb and gutters. There should be no other upstream BMPs in the drainage basin, including roadside swales that will filter pollutants, especially gross solids, before they enter the BMP.

The monitoring approach that was developed and applied in this study measured water column pollutant removal performance based on flow composited water column autosamplers as well as masses that accumulated in the baffle box as gross solids. The monitoring approach demonstrated that the solids which accumulate in a baffle box must be included in an overall assessment of pollutant removal effectiveness of the baffle box. In some cases, mass removal in accumulated solids was significantly greater than water column mass removal. Use of a Derived Efficiency (DE) provided an index of pollutant reduction efficiency that incorporated accumulated solids and water column monitoring, resulting in a net positive retention of nitrogen and phosphorus. DE is a more useful indicator of baffle box treatment performance than water column EMC methods.

Field monitoring of four full scale baffle boxes resulted in the following findings:

- The average DE for non-dissolved stormwater solids removal was 43.6%, ranged from 2 to 83%, and was higher for Type 2 than Type 1 baffle boxes.
- The average DE for nitrogen removal was 9.8%, ranged from 0.03 to 28%, and was higher for Type 2 than Type 1 baffle boxes.
- The average DE for phosphorus removal was 8.9%, ranged from .06 to 19%, and was higher for Type 2 than Type 1 baffle boxes.
- Watershed characteristics and the presence of sieve screens significantly affected the differences in DE between the Type 2 and Type 1 baffle boxes.
- EMC removal efficiencies for total suspended solids averaged 8.5, 35.1, 12.3, and -38.5 %, respectively, for Rockledge, Sarasota, Lincoln, and Parkway baffle boxes.
- EMC removal efficiencies for total nitrogen averaged -11.3, 30.6, -8.3 and 5.6 %, respectively, for Rockledge, Sarasota, Lincoln, and Parkway baffle boxes.
- EMC removal efficiencies for total phosphorus averaged -8.2, 21.6, 1.5 and -15.3 %, respectively, for Rockledge, Sarasota, Lincoln, and Parkway baffle boxes.
- EMC removal efficiencies for fecal coliforms averaged -28, 13, -89 and -4.2 %, respectively, for Rockledge, Sarasota, Lincoln, and Parkway baffle boxes.
- Total polycyclic aromatic hydrocarbons ranged from non-detect to 15.5 mg/kg dry solids in materials collected from the baffle box bottom chambers.
- Total polycyclic aromatic hydrocarbons ranged from 20 to 53 mg/kg and 28 to 70 mg/kg in sieve screen materials greater and less than 1 mm, respectively.

When measured by the EMC method, Type 1 baffle boxes provided average reductions of 13.1%, -1.3%, -6.9%, and -46.8% for TSS, TN, TP, and fecal coliforms respectively. When using the DE methodology there were average mass removals of 19.9%, 0.5%, and 2.28% for Total non-dissolved solids, TN, and TP respectively.

Parameter	EMC	DE
TSS	13.1%	n/a
Total non-dissolved solids	n/a	19.9%
TN	-1.3%	0.5%
TP	-6.9%	2.28%
Fecal coliform	-46.8%	n/a

Table 32 – Type 1 baffle box removal efficiency using EMC and DE methodology

Type 2 baffle boxes showed higher pollutant removal effectiveness than Type 1 baffle boxes, with average EMC removals 21.8% for TSS, 9.6% for TN, 6.7% for TP, and -118% for fecal coliforms. Using DE calculations the Type 2 baffle boxes averaged 67.2% TSS removal, 19% TN removal, and 15.5% TP removal.

Parameter	EMC	DE
TSS	21.8%	67.2%
TN	9.6%	19%
TP	6.7%	15.5%
Fecal coliform	-118%	n/a

Table 33 - Type 2 baffle box removal efficiency using EMC and DE methodology

The screens in Type 2 baffle boxes trapped organic debris that would not be filtered in Type 1 baffle boxes. In watersheds that have a significant amount of tree canopy coverage, Type 2 baffle boxes give a greater nutrient removal than Type 1 baffle boxes due to the ability to filter leaves. Grass clippings were not a significant source of organic debris at the four sites monitored, indicating that public education programs to train residents not to place grass clippings in streets appear to be successful. During the monitoring program residents were observed several times blowing grass clippings into the yards. Oak leaf and pine needle accumulations were the significant source of organic debris in these watersheds.

At three of the four baffle box locations, fecal coliform concentrations were observed to be 44% - 61% higher in the effluent than the influent. Baffle boxes and other vault type BMPs that store interevent water act as septic tanks, promoting bacteria growth and low DO in the nutrient laden water. If fecal coliform is a parameter of concern for a waterbody, use of a baffle box or any water storing vault box can lead to increased fecal coliform counts to waterbodies.

Pollutant loadings vary widely among watersheds. Pollutants are present in the water column, street sediments, and in organic debris. In the Rockledge watershed, masses from leaves and sediment were 53.4 times greater than water column solids masses. In the Sarasota watershed sampling failures did not allow an accurate comparison of water column and gross solids masses. In watersheds with significant tree coverage, selection of BMPs that remove leaves from stormwater runoff can reduce nutrient discharges. Selection of BMPs that keep leaves in a dry state will provide greater nutrient removal than BMPs that store leaves in a wet condition.

While Type 2 baffle boxes kept leaves out of the water filled vault, the accumulation of leaves in the baskets filtered sediment creating a semi-pervious liner that stored water for several days, enabling leaves to leach nutrients slowly into the vault. In addition, the inherent design of screens that enabled high flow bypass for flood reduction allowed significant masses of leaves to fall from the screens into the vault boxes. It is worthwhile to mention that without the screens almost all leaves would wash through the box and end up in the receiving water where they would leach their entire nutrient mass.

The ability of leaves to leach nutrients even from a Type 2 baffle box demonstrated the importance of cleaning BMPs. The Sarasota baffle box screen was observed to completely fill with leaves after a small rain event. Even with the limited documentation of leaf accumulations from the Sarasota baffle box, 3586 pounds of leaves and sediment were collected. At the Rockledge baffle box 1,378 pounds of debris were collected from the screens. In watersheds with high leaf falls, it is recommended that baffle box screens be cleaned after every rain event in order to maximize nutrient reduction and prevent nutrient leaching from Type 2 baffle boxes.

Baffle box performance could be improved if there was a way to pump or bleed off chamber water between storms. The nutrient leaching and bacterial growth problem would be eliminated. The trade off for such an improvement would be moving from a passive design to an active mechanical design with maintenance and costs for pumps, electricity, and trained personnel. Passive low maintenance technology has been taken about as far as possible. Further advances in pollutant treatment will require mechanical and/or chemical technology similar to the wastewater industry.

Another recommendation related to the maintenance of the baffle box is to set up a clean-out schedule based on the observed needs of the individual baffle boxes, rather than a set quarterly or monthly clean out schedule. Some of the baskets in the study filled completely after a single rain event. Better tracking of the amount of organic material removed from the boxes can also aid in directing more maintenance efforts towards boxes that need frequent clean outs. This will aid in optimizing effectiveness.

Based upon the findings of this report, the following criteria are recommended for use of Type 2 baffle boxes:

1. When pollutants targeted for reduction in the watershed are nutrient based,
2. When fecal coliform reduction within the watershed is not a goal,
3. When the streets in the watershed have curb and gutters,
4. When there are no upstream BMPs such as ponds, exfiltration trenches, swales, inlet traps, and
5. When tree canopy coverage in the watershed exceeds 25%.

In watersheds with curb and gutter, an alternative to the use of Type 2 baffle boxes is installing inlet traps at all inlets. These BMPs act as a form of source control by reducing the leaching potential from trapped organic debris. Allowing organic debris to dry in an inlet trap can act as a unit process as nutrients are released to the atmosphere (England, 2008.) A limitation of inlet traps is that they trap little sediment and have much smaller debris trapping capacity than a Type 2 baffle box. However, they have much smaller drainage basins than a baffle box typically installed at the end of a watershed. Inlet traps will also require more frequent maintenance than a baffle box. Maintenance of a baffle box requires an expensive vacuum truck, while cleaning an inlet trap can be accomplished with by hand or a small truck mounted vacuum pump. Inlet traps cost about $1,000 while baffle boxes will cost approximately $50,000 for installation and road reconstruction. Inlet traps trade off lower upfront cost with higher maintenance frequency than a baffle box.

Another alternative BMP that could be used to collect gross solids is street sweeping. This form of source control removes 100% of the pollutants associated with the mass of material removed, does not require expensive engineering and construction, and is promoted by FDEP with special credits toward reducing TMDL load allocations. The City of Pensacola's Surface Water Quality Assessment (England, 2009) documents that the City's once a week street sweeping program collects an average of 5,734,865 pounds of sediment and gross solids. Based upon testing of street sweeping material by the City, the collected mass equates to

2,265 lb/yr of TN and 720 lb/yr of TP removed from the streets. Using an annual street sweeping program cost of $185,000, TN annual removal costs are $82/lb and TP removal costs are $257/lb.

To improve the quantification accuracy of stormwater pollutant reductions by BMPs that accumulate gross solids, a comparison of laboratory protocols and sampling procedures was made to improve the methodologies to quantify solids that accumulate in those BMPs and characterize their pollutant concentrations. Based on the limited number of samples and disparity of results, a recommendation to use solids based analytical methods for gross solids could not be made. This issue requires further investigation.

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